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UDC 535.215

Characteristics and Applications of Photo-Electric Cells

By F. A. BENSON, D.Eng., Ph.D., A.M.I.E.E., M.I.R.E. *(Member)*

Summary

The paper deals first with the theory of photo-emission and the properties of photo-emissive cells. The various types of cathode which have been developed are described. Information is then presented on gas-filled cells and photo-electric multipliers. Mention is made of colour response, fatigue effects, dark current, noise, frequency response and associated circuits. The mechanisms and characteristics of various types of photo-voltaic and photo-conductive cells are then discussed, and some details of semi-conductor photocells are included. The applications of photocells to photometry, spectrophotometry, astronomy, radiation detection, recording of transient optical phenomena and in reflectometers, fluorometers, refractometers, colorimeters and turbidimeters are briefly discussed. Some infra-red photo-electric equipment is mentioned and finally a large number of miscellaneous photocell applications are listed.

(1) Introduction

The electrical properties of a conductor may alter in different ways when electromagnetic radiation falls on its surface, and photocells are devices employing these effects. They can be classified as follows, depending on which electrical effect their operation relies :—

(*a*) Photo-emissive—electrons are liberated from a suitably prepared surface by the radiation.

(*b*) Photo-voltaic—incident radiation causes an e.m.f. to be set up at the cell terminals which in turn gives a current flow in an external circuit.

(*c*) Photo-conductive—incident radiation causes a change in electrical conductivity of a material.

Many applications of photocells are well known. Cells may operate almost any kind of electrical or mechanical device through suitable amplifiers and relays. They may cause a device to react to almost any light-intensity variation and will respond to radiation in the visible, infra-red or ultra-violet parts of the spectrum. Here the properties and applications of the above three types of cell are discussed and mention is made of semiconductor photocells, but nothing is included on cell manufacture, television camera tubes and cells based on the photoelectromagnetic effect in indium antimonide[1, 2] or other materials[3, 4].

(2) Photo-Emissive Cells

The photo-emissive effect was discovered by Hertz[5] in 1887 and shortly afterwards Hallwachs[6] observed that ultra-violet radiation caused the liberation of negative charges from a zinc electrode. In 1889 Elster and Geitel[7] produced the first photoelectric cell.

(2.1) Theory of photo-emission

When light falls on the photosensitive cathode of the cell of Fig. 1 electrons are liberated and are attracted to the anode, giving a current in the external circuit. If corresponding readings of current (I_a) and anode-cathode voltage (V_a) are plotted for a fixed intensity and wavelength of the incident light, a characteristic curve similar to one of those shown in Fig. 2 is obtained. If measurements are made with monochromatic light but of different intensities, a family of curves as in Fig. 2 results. If the wavelength of the light is now changed and the intensity is adjusted to keep the current at a fixed value in the positive V_a region the family of curves of Fig. 3 is obtained.

For a sufficiently positive voltage on the anode the current reaches saturation for a given light intensity and this saturation current is proportional to the intensity. Saturation at zero anode voltage can only be obtained with experimental cells where the cathode is almost completely surrounded by the anode. Electrons continue to reach the anode in decreasing numbers as V_a is made increasingly negative until at a certain critical voltage V_o (Fig. 2) the current I_a falls to zero. V_o depends on the colour of the light but not on its intensity. The curves indicate that electrons are emitted with varying kinetic energies, enabling them to reach the anode against a retarding electric field. Since V_o is the same for all the curves of Fig. 2 it suggests that the maximum electron emission

The author is with the University of Sheffield. The manuscript of this paper was first received on August 8, 1957, and in final form on February 14, 1958. The paper was presented at a meeting of the Society held in London on April 15, 1958.

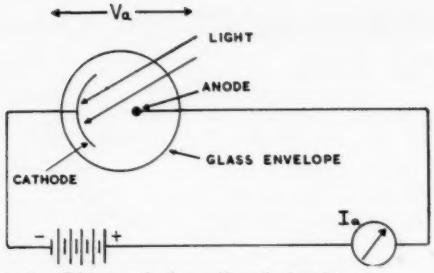

Fig. 1. Photo-emissive cell and circuit.

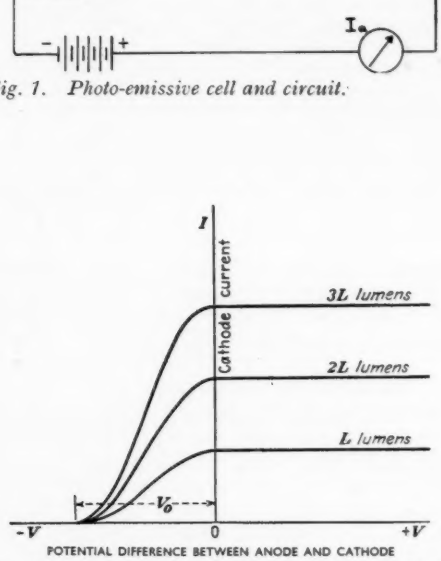

Fig. 2. Current-voltage characteristics of photo-emissive cell for various intensities of illumination.

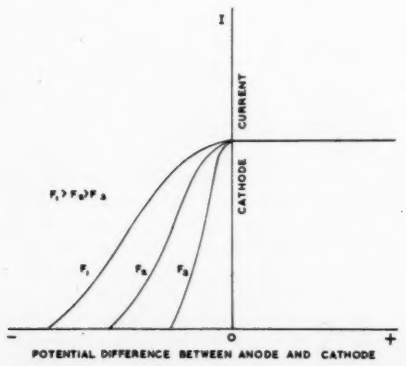

Fig. 3. Current-voltage characteristics of photo-emissive cell for various frequencies of illumination.

velocities are the same for all light intensities.

The photo-emissive effect is practically instantaneous; emission commences in a time less than 3×10^{-9} sec. after the cathode is illuminated. Current ceases in less than 10^{-8} sec. after the illumination is removed. Sensitivities of vacuum photocells range from about 5 to 50 μA/lumen. Most cells have a small temperature coefficient, the sensitivity decreasing with rise of temperature which may be about 0.2 per cent. per deg. C[8]. The sensitivity may vary over the cathode surface[8], an important consideration if the cathode illumination is uneven. Special cells have been designed to achieve the highest possible linearity[8]. Discontinuities in the saturation curves of photocells have been discussed by Preston and Gordon-Smith[9] and certain undesirable phenomena under weak illuminations have been observed by Sugawara[10].

Electron emission from a body subjected to light implies that the radiation energy exists in packets or bundles which are known as photons or quanta. The photon energy depends on the frequency f but is otherwise constant and is given by hf where h is Planck's constant (6.624×10^{-34} joule-sec.). Einstein[11] postulated that light energy is absorbed in a quantised way, the energy of a photon being changed to kinetic energy of an electron inside the metal. The electron can acquire sufficient energy to overcome the potential barrier at the metal surface and so escape. Einstein's photo-electric equation is :—

Emission energy of photo-electron $\leq hf - e\phi$, where e is the electronic charge and ϕ is the work function. The inequality sign is introduced because an electron may not travel in a direction normal to the metal surface. Thus, on introducing numerical values for h and e, and since f = velocity of light/wavelength of light, the voltage E to which the emission energy of the photo-electron corresponds is found to be :—

$$E = \frac{12{,}400}{\lambda} - \phi$$

where λ is the wavelength of the light in Å and ϕ is in volts. When $E = 0$, $\lambda = 12{,}400/\phi$ so that for every photocathode there is a certain threshold wavelength of the exciting light beyond which emission is not possible. Surfaces which will respond to long-wave radiation at the red end of the spectrum ($\lambda > 7000$Å) must have a work function $< 12{,}400/7000$ i.e. < 1.77V. The threshold wavelength for tungsten is 2,735Å so that tungsten will not respond to visible or even to long-wave ultra-violet radiations.

Discussions of the value of Einstein's equation and of later theories have been given by Rodda[12] and Sommer[13]. Further information on photo-emission and photo-emissive cells can be found in publications by Zworykin and Ramberg[14], Spangenberg[15], Lovell[16], Summer[17] and in certain of those listed in the Bibliography.

(2.2) Colour response

Cells do not show uniform sensitivity over the whole spectrum but the response curves usually exhibit one or more maxima (Fig. 4). The heights and positions of the maxima depend on the surface, but individual cathodes of a given kind are not identical. The silver-oxygen-caesium (Ag–O–Cs) cell, for example, has at least two maxima in its spectral curve, one in the near infra-red at a wavelength of about 8,000Å, and a second one in the ultra-violet (not shown in Fig. 4) near 3,500Å. The antimony-caesium (Sb–Cs) cathode gives an entirely different response, its maximum sensitivity being in the blue region of the spectrum, around 4,600Å. The spectral response curve depends on the temperature[18].

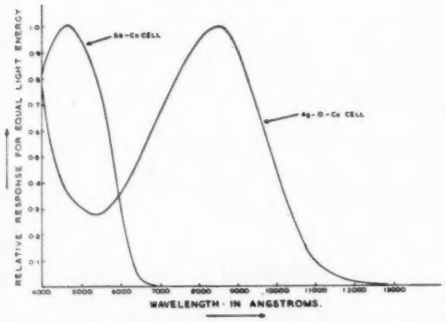

Fig. 4. Relative spectral response of Ag-O-Cs and Sb-Cs cells. Peaks adjusted to unity.

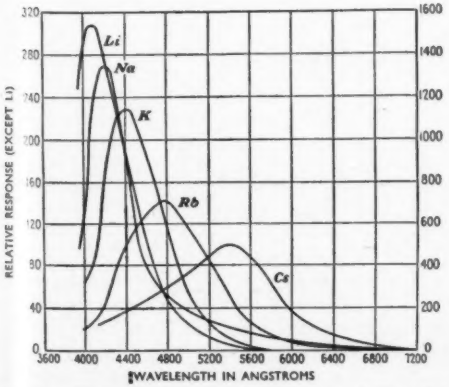

Fig. 5. Photo-electric response curves of the alkali metals.

(2.3) Types of photo-electric cathode

(2.3.1) *Pure-metal cathodes*

Early cells used cathodes of pure metals having large work functions and poor efficiency. They are not sensitive to visible light, the threshold wavelength being in the ultra-violet region.

(2.3.2) *Alkali cathodes*

The earliest cells responding to visible light had alkali-metal cathodes, giving low efficiencies. The spectral-sensitivity curves and the quantum yields of cathodes of the same type vary widely, probably due to impurities. Figures obtained by different investigators for the wavelengths of maximum sensitivity of lithium, sodium, potassium, rubidium and caesium, have been given by Sommer[13], and response curves for these metals (reproduced in Fig. 5) have been published by Seiler[19] and Spangenberg[15]. The maximum-sensitivity point is moved from shorter to longer wavelengths in the sequence from the lightest to the heaviest metal: elements having the greatest atomic volume tend to have the lowest work function. As the atomic number of the element increases, the maximum sensitivity decreases and the resonance peak becomes broader.

(2.3.3) *Alkali-hydride cathodes*

Certain alkali-metal cathodes can be "sensitised," increasing the photo-electric response, by forming hydrides in a hydrogen glow-discharge. Such cathodes show strong selective maxima in their response curves in the blue and ultra-violet region of the spectrum.

(2.3.4) *Composite cathodes*

The cathodes listed above are now mainly of historical interest owing to their low quantum yield. Composite cathodes, where an alkali metal is deposited on a specially treated base layer of another metal, are of very great importance, however, and the Ag–O–Cs is one of this type, having a threshold wavelength in the infra-red, greater than 12,000Å. Detailed information on the manufacture of this cell has been given by Sommer[13] and Lovell[16], including the process due to Asao and Suzuki[20] for obtaining appreciably greater sensitivities.

For applications where the back of the photo-

sensitive layer is illuminated and photo-electrons are liberated from the front, the semi-transparent Ag–O–Cs cathode is used. The colour response of such a cell can be changed considerably by employing a very thin layer. Good thin-film-alkali vacuum cells are stable over long periods if not overloaded[8].

(2.3.5) *Alloy cathodes*

The antimony-caesium cathode is the most important of the alloy cathodes because of its good sensitivity. Gorlich[21] discovered in 1936 that antimony forms a highly photo-sensitive alloy with caesium when exposed to caesium vapour. The same effect has been observed with alloys of arsenic, bismuth, thallium, lead and gold with caesium and other alkali metals, and alloys of antimony with alkali metals other than caesium have been produced. Details of Sb–Cs cell manufacture are published[13, 16]. The threshold wavelength for the Sb–Cs cell is at about 6,500A in the visible portion of the spectrum. The sensitivity is much greater than for the Ag–O–Cs cathode. Sb–Cs cathodes can also be made as semi-transparent layers, but at low temperatures these yield subnormal response[22].

Another cathode of considerable interest is the bismuth-oxygen-silver-caesium one whose sensitivity lies between those of Sb–Cs and Ag–O–Cs surfaces.

A vast amount of literature on the photo-emissive properties of many different kinds of surface exists, and some of this is listed in the Bibliography. New photo-emissive cathodes of high sensitivity have been described by Sommer[23].

(2.4) Gas-filled cells

Photocell sensitivity can be increased considerably by introducing a small quantity of gas into the bulb so that ionization takes place. An inert gas is used because of the great chemical reactivity of the alkali metals incorporated in the cathodes. The gas should also have a low ionization potential, so argon is normally used at a pressure less than 1 mm. of mercury, although other gases have been employed for special applications. The mechanism of gas amplification in cells is probably well known and will not be dealt with further here.

Since the number of ionizing collisions increases with the applied voltage, the gas-filled cell does not have a saturated voltage-current characteristic as does the vacuum cell (Fig. 6). An increase of cell voltage leads to an increase of amplification, but this is limited because above a certain voltage a self-maintained discharge commences in the cell. Also, the cathode could be destroyed by ion bombardment, although potassium-hydride cathodes overlaid with a monatomic layer of potassium have been developed[24] to overcome this effect. At high illumination levels, the current in a gas-filled cell is not proportional to the illumination. Even under low illumination, some departure from linearity is found (Fig. 7) but the distortion resulting from this is not serious. Further information on gas-filled cells can be found in Reference [8].

(3) Photo-electric Multipliers

Gas-filled cells have low amplification factors

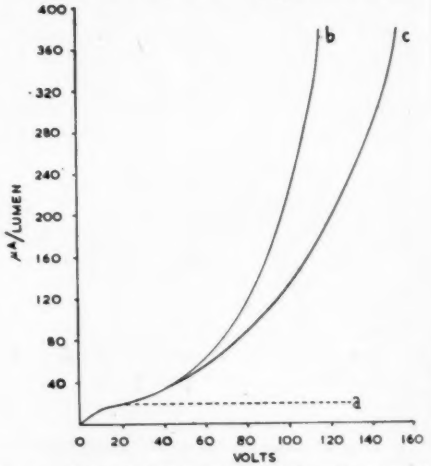

Fig. 6. Characteristics of gas-filled cells at various pressures. Curve a is for a vacuum cell, i.e. pressure = 0.
Pressure in cell (b) is greater than in cell (c).

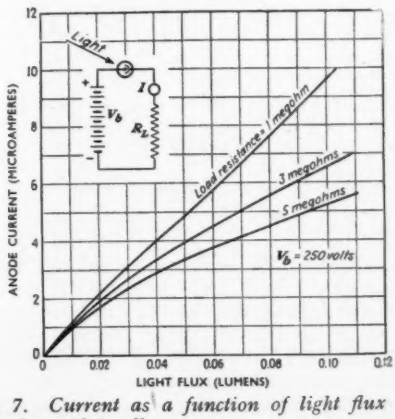

Fig. 7. Current as a function of light flux in a typical gas photocell.

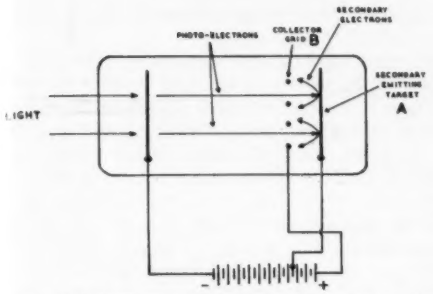

Fig. 8. Illustration of principle of operation of the photo-multiplier.

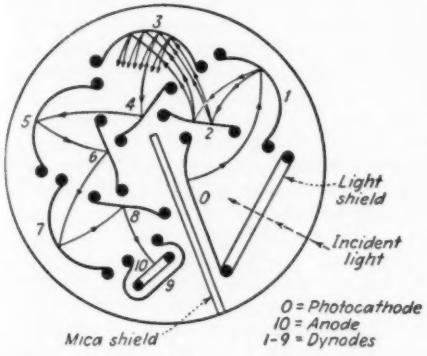

Fig. 9. Structure of photo-multiplier.

and poor frequency responses. These limitations have led to the development of photo-electric multipliers where the original photocurrent is amplified by using, as Slepian[25] suggested in 1919, the phenomenon of secondary emission.

The secondary-emission process is well known[12, 15, 16]. When primary electrons strike a metal they can liberate secondary electrons. The secondary-emission yield coefficient (i.e., the average number of secondary electrons released by each primary) depends on the primary-electron energy, the angle of incidence and the nature and work function of the surface. The maximum yields of pure metals are low (of order 2) but much larger yields (5 to 20) can be obtained from special surfaces such as Ag–O–Cs, Sb–Cs, and also from oxidised-alloy surfaces[26]. Secondary emission is an almost instantaneous process[27].

The principle of the photo-electric multiplier is illustrated in Fig. 8. Light falling on the photocathode liberates electrons which are accelerated by the positive voltage and strike electrode A. Secondary electrons liberated at A may be collected by a second electrode B. Alternatively, the electrons produced at A may be further accelerated to strike a second target, thus releasing more electrons. This process can be repeated many times inside a single envelope and the final amplified current collected on the last electrode. If the current amplification in each stage is k, the total amplification in n stages is k^n. Very large amplifications can therefore be achieved in multi-stage tubes (cells with up to 19 stages have been built[18]).

An enormous number of publications and patents deal with the structure, design and performance of photomultipliers; it is impossible to discuss the contents of these in this paper. The reader should therefore consult the book by Rodda[12], References [13] and [15] and the publications listed in the Bibliography.

Only one type[29] of multiplier will be described. A cross-section through its electrode system is shown in Fig. 9. An ingenious shape and arrangement of the electrodes (dynodes) determined by tracing electron paths with a rubber membrane model[30], ensure collection by a target of all secondary electrons produced at the preceding dynode. Such a tube has a k factor of 5 to 6 and an overall sensitivity up to 5A/lumen.

Limitations of photomultipliers are :—

(*a*) the allowable output current is limited because of the possibility of overheating the final stages.

(*b*) the total amplification factor is very sensitive to small changes of electrode voltages because secondary emission at each dynode depends on the velocity of the impinging primary electrons.

(4) Fatigue

Photocells show changes in sensitivity under certain conditions. The fatigue occurring when a cell is exposed to illumination and with a positive voltage on the anode is of main interest. Under such conditions electron emission may cause slight changes of the cathode surface, altering the sensitivity. Fatigue is very pronounced in gas-filled cells, probably due to the effects of ion bombardment at the cathodes or liberation or adsorption of gas by the electrodes and envelopes.

If a cell is greatly overloaded with illumination when delivering current, the sensitivity is reported[31] to fall rapidly, and does not recover. For example, Sb–Cs cells lost 50 per cent. of their initial sensitivity on illumination with 1,000 lm/ft.^{2}. A cell on open-circuit is not so affected unless the illumination is so high that appreciable surface heating occurs. Sommer[13] has given approximate figures for the safe loading of cells under working conditions. Fatigue in cells has been discussed

by Kuwabara[32] and in photomultipliers by Wilson[33] and Lenouvel and Daguillon[34].

(5) Dark Current

When a photocell is in the dark, current still flows and this must be kept small if very weak signals are to be detected. The dark current is caused by thermionic emission from the cathode or by electrical leaks. The latter can be made small by using long leakage paths, or in very special cases by fitting guard rings.

Since photocell cathodes have low work functions, they are good thermionic emitters. For example, at room temperature, the thermionic emission from a Ag–O–Cs surface is about 10^{-9}A/cm^2. Cathode area should, therefore, be as small as possible. An enormous reduction in thermionic emission can be achieved by cooling the cell in, say, liquid nitrogen.

(6) Associated Circuits and Frequency Response

The galvanometer in the basic photo-emissive circuit of Fig. 1 is usually replaced by a load resistor R_l (Fig. 10) and the photocurrent flowing through R_l produces a voltage V_l which is applied to an amplifier valve grid. For very slow variations of the illumination or for D.C. measurements, and for a certain photocurrent, V_l increases with R_l. R_l cannot be increased indefinitely, however, because of limits set by grid-cathode insulation of the valve and by cell dark current. Electrometer valves may be used in the first stage of the amplifier where great sensitivity is desired.

If the frequency of the illumination variations is high enough, the shunting effect of the valve input capacitance C must be taken into account. For example, if $C = 30\mu\mu$F and $R_l = 1\text{M}\Omega$, the input signal to the valve at 1 Mc/s is about 1/200 of the signal at 50 c/s[16]. Hence, a suitably small value of R_l must be used or frequency-response correction must be made in the amplifier circuit. AC amplifiers are usually more convenient to use than DC ones, so the incident light is often periodically interrupted.

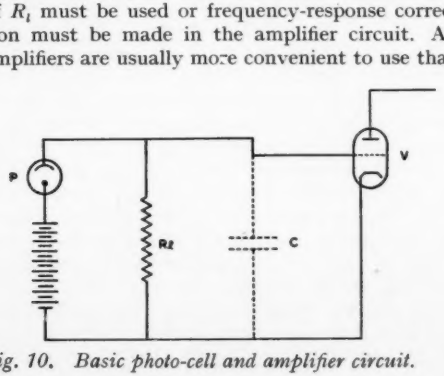

Fig. 10. Basic photo-cell and amplifier circuit.

In many applications the light-source intensity may change very rapidly. It is appropriate to consider, therefore, whether the photocurrent will also change at the same frequency as the source. In vacuum cells the only limit to frequency response is the electron transit time between the electrodes. For parallel-plane electrodes with a spacing of 3 cm. and an anode voltage of 100V, the electron transit time is about 10^{-8} sec., so frequency response is affected at frequencies greater than about 100 Mc/s[13]. Lower anode voltages and larger electrode spacings reduce the critical frequency. The frequency response of a gas-filled cell is much worse than for a vacuum cell, the distortion arising from the time involved in the formation of the ions and their large transit time. The response of a typical cell falls off at frequencies beyond about 100 c/s and at 10 kc/s is only about 70 per cent. of the low-frequency value.

If a valve amplifier is used to provide additional amplification the overall frequency response is only as good as the amplifier response.

(7) Noise

At very low illumination levels the phenomenon of random fluctuations, or noise, becomes important. The fluctuations are superimposed on the signal and can be so large that the signal is unintelligible. It is desirable, therefore, to keep the signal/noise ratio high but the actual requirements depend on the accuracy desired and the nature of the measurement. This paper does not allow of a detailed discussion of noise sources, but the total noise energy at the grid of the first valve of the amplifier arises from shot effect in the photocurrent and the first valve, thermal agitation noise in the grid circuit, and flicker effect in the first valve.

Except when the emitted photocurrents are large, the signal/noise ratio of the photomultiplier is superior to that of a normal photocell with its associated resistor - amplifier combination[15].

(8) Photo-voltaic cells

The photo-voltaic effect was discovered by Becquerel[35] in 1839. Development of modern photo-voltaic cells began with Grondahl's work[36] on copper-oxide rectifiers in 1926-7.

A high-resistance barrier-layer between two materials is essential for the occurrence of the photo-voltaic effect. The layer allows current to flow easily only in one direction, and its action is

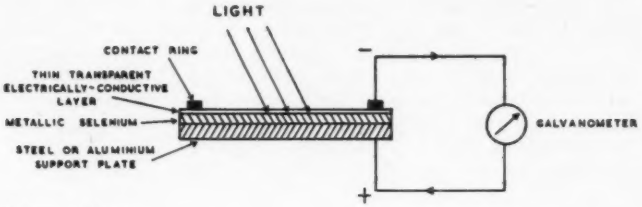

Fig. 11. Photo-voltaic cell.

well known in connection with rectifiers. Early cells using copper/copper-oxide materials were called "back-wall" types because the light penetrated through the oxide to the barrier layer between the oxide and the copper base. Nowadays more sensitive "front-wall" cells are used, in which the barrier layer is between the front surface and a semi-transparent metal layer on the semi-conductor (Fig. 11). Cells having artificial barrier layers have also been tried. The selenium cell is now commonly used because of its good sensitivity. Some typical characteristics of a cell are shown in Figs. 12 to 16. In Fig. 12 at low illumination the voltage increases almost linearly with illumination. Fig. 14 shows that the smaller the external resistance the larger the useful current, but the smaller the power output. Characteristics for large external resistances are far from linear. The response curve of the selenium cell has a peak at a wavelength of about 5,700Å, the threshold wavelength is greater than 7,500Å, and the cell has reasonable sensitivity even at 3,000Å. The sensitivity is about 500 μA/lumen.

Photo-voltaic cells are unsuitable for high-frequency work because of their poor frequency response, and they show a large reversible fatigue effect. Preston[37] reports that the sensitivity of selenium cells falls rapidly to about 75 per cent. of its original value when illuminated with light having a wavelength greater than 6,400Å, but the cells recover quickly in the dark.

Details of thallium-sulphide photo-voltaic cells have been given by Nix and Treptow[38] and of lead-sulphide photo-voltaic cells by Bose[39], Lange[40], Gruetzmacher[41] and Fischer, Gudden and Treu[42]. The properties of the German grauze lead-sulphide cell have been discussed by Lovell[16]. Further details of photo-voltaic cells, including information on drifts, uniformity of the sensitive surface, the effect of obliquity of the incident radiation and the effect of temperature can be found in the publications listed in the Bibliography.

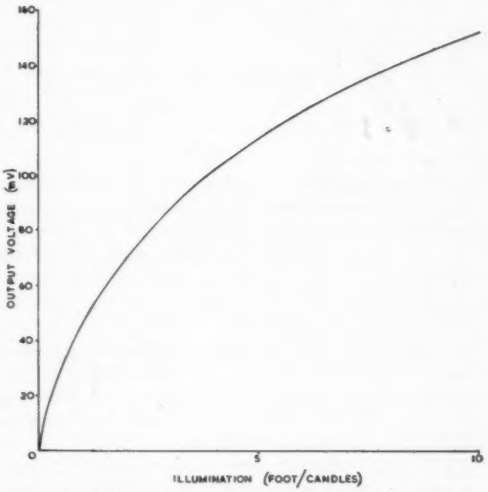

Fig. 12. Open-circuit voltage/illumination characteristic of photo-voltaic cell.

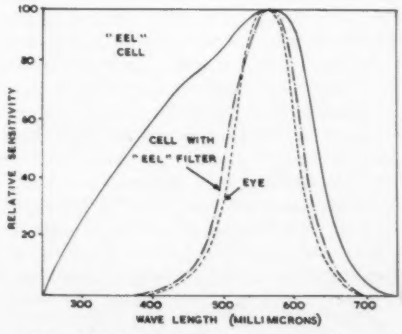

Fig. 13. Spectral-response curve of a typical photo-voltaic cell.

(9) Photo-Conductive Cells

Smith[43] first described the photo-conductive

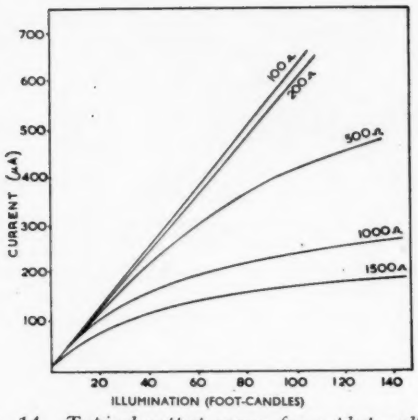

Fig. 14. Typical output curves for a photo-voltaic cell.

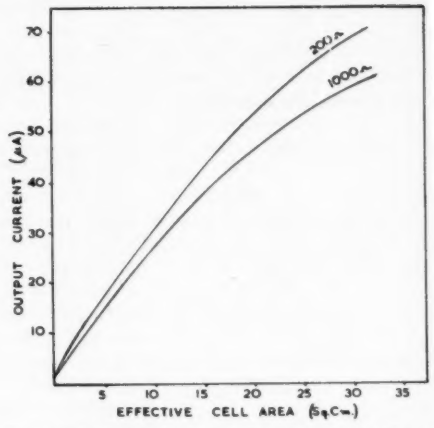

Fig. 15. Current/cell-area curves for typical photo-voltaic cell when subjected to an illumination of 5-ft. candles.

effect in 1873. Extensive studies of the effect have been made since then and an early detailed survey has been given by Nix[44].

A photo-conductive cell arrangement is shown in Fig. 17. When light falls on the cell a current flows. Electrons liberated inside the material move towards the anode through the crystal lattice. The efficient photo-conductive materials known include pure selenium and the sulphides, selenides and tellurides of several elements. The response of photo-conductive cells is mainly in the infra-red and red parts of the spectrum.

Thallium-sulphide eells, described by Case[45] in 1920 have since been developed in many countries. A grid arrangement for the electrodes is used to obtain a resistance of a few MΩ's. There is a large change of resistance with temperature. A typical cell of this kind will have a maximum response at about 0.9μ.

Lead-sulphide cells were developed in Germany. Probably the most interesting feature of the cell is that its spectral sensitivity extends to about 3.5μ with a maximum response around 2.7μ. Considerable differences in spectral sensitivity occur from cell to cell and there are large changes of resistance with temperature as with thallium-sulphide. Speed of response is good. Some publications dealing with photo-conductivity and lead-sulphide cells are listed in the Bibliography. A single-crystal photodiode of lead sulphide has been examined by Bate, Bennett, Hilsum and Starkiewicz[46, 47]. Photo-effects in lead sulphide and copper selenide have been discussed by Popov[48].

Lead selenide and lead-telluride cells were the subject of secret research work in Germany from

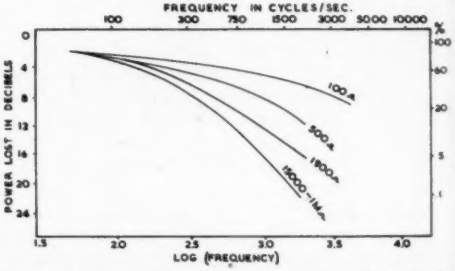

Fig. 16. Frequency response curve of a typical photo-voltaic cell.

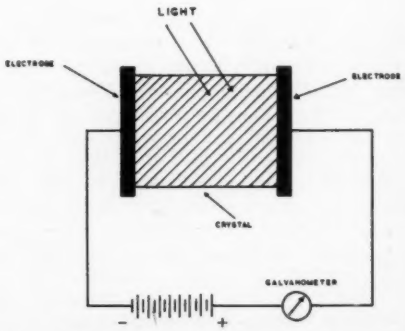

Fig. 17. Photo-conductive cell arrangement.

1938 for several years. Lead-telluride cells for infra-red spectroscopy have been described by Simpson, Sutherland and Blackwell[49], and the conductivity of evaporated films of lead selenide has been studied by Simpson[50]. Information is also available on the photo-conductivity of bismuth-sulphide, bismuth-telluride, silicon, indium-antimonide, cadmium-selenide, zinc-telluride, indium-doped silicon, aromatic hydrocarbon crystals, and cadmium-sulphide, and a paper on the reduction of noise in photoconductive cells has been published by Burgess[51] . A ceramic material consisting of titanium dioxide with additions also exhibits marked photo conductivity under specified conditions[17]. Photoconductive effects in indium-arsenide have been observed by Hilsum[52]. Papers by over forty authors which were read at a Photoconductivity Conference in Atlantic City in 1954 have also been published[53].

(10) Semi-conductor Devices

Many of the characteristics and applications of transistors are well known[54]. The ordinary transistor is protected from light by an external coating because the current flowing in a semi-conductor like germanium is a function of the quantity of light falling on it. The photo-transistor takes advantage of this phenomenon and also amplifies the initial photo-electric current. Good introductions to the subject of semi-conductor photocells have been given by Shive and Zuk[55], and elsewhere[54]. Shive and Zuk[55] describe a cell whose active element is simply a p-n junction with contacts to the ends of the p and n sections. A voltage bias is applied to the two terminals with the n end positive, and in the dark the junction offers high resistance to current flow. When light falls on the junction the resistance is lowered and an increased current flows. The magnitude of the current is approximately proportional to the incident light flux.

The cell responds from a limiting region in the ultra-violet part of the spectrum, where the encapsulating plastic becomes opaque, to another limit in the infra-red region where the germanium becomes transparent. Cell output depends not only on light intensity and wavelength but also on where the light is incident on the germanium slab. If a small spot of light is focused on the germanium surface and is moved from one end of the material to the other, the output current varies with the light-spot position. The response is a maximum when the light is focused on the junction, but falls off as the light spot is moved away in either direction. The speed of response also depends on the position of the light-spot, but is very rapid when light falls on the junction. The linearity of the cell is comparable with that of a vacuum photocell, while the output current for a given light flux is from 10 to 20 times higher.

Further information on semi-conductor cells can be found in Reference[17] and in the publications listed in the Bibliography. Some of these include detailed discussions of the mechanisms involved in the photo-processes in germanium.

(11) Applications

The number of possible applications of photo-cells in industrial practice is enormous and covers a very wide field. There are few areas of human activity in which photo-electricity does not play a part. Some of the applications are briefly discussed below.

(11.1) Photometry

The objectives of photometry are well known. Measurements consist of comparing, in some way, the unknown illumination with a known standard. Problems encountered in such measurements using photocells are, variations in spectral response between cells even of the same type, lack of constancy of response, and linearity of photo-current with incident light flux. Gas-filled cells are not well suited for measurement purposes, but vacuum cells will give reliable results if special precautions are taken. When the spectral emissions of the standard and unknown sources are different exact measurements cannot be obtained unless these emission characteristics and the photocell colour response are known. Faulty colour response can frequently be corrected by a method described by Winch and Machin[56], in which the light from the source is split into a spectrum and focused in the plane of a suitably shaped opaque template which intercepts a desired amount of light of each colour.

Portable barrier-layer-cell light meters mounted on extensible poles have been used to explore inaccessible places. Such a cell with a hole bored through its centre to transmit incident light may be employed to measure light reflected in a forward direction by "cat's eyes" in roadways[57]. The total biologically-active ultra-violet radiation, at a given place, from the sun and sky has been determined with a special zirconium photocell[58], whose response covers approximately the spectral band of interest, namely 2900 to 3200Å. Naish[59] has discussed photometry with photo-multipliers.

(11.2) Spectrophotometry and astronomy

In spectrophotometry only the energy contained in a narrow band of the total spectral emission of

the source is available, so photocurrents are very small and the photo-multiplier is useful. There are two main types of spectro-photometer, one where a photocell with calibrated spectral response replaces the eye, the other employing an instrument for automatically plotting the spectral transmission or reflection of a specimen through the whole spectral range.

Photoelectric spectrophotometers have very rapid response and so are useful for finding the spectral distribution of the light emitted during the decay time of phosphors or the spectral lines emitted at different phases of an arc-discharge in a gas. The spectral distributions of the luminescence of materials such as cloth samples have been obtained with ultra-violet excitation([60]). Spectrophotometers have been described and used for spectrochemical analysis by many authors.

Only very small light energies are available in the field of astronomic photometry and spectrophotometry. Photo-emissive cells with electrometer valves have been used for such applications, and the measurement of light from stars with photomultipliers at liquid-air temperature has been discussed([61]). Colours of stars have been observed using colour filters and Sb–Cs surfaces. Photo-electric methods have also been used to determine star positions, numbers and sizes, as well as colours and intensities, and the photomultiplier is obviously very useful for such purposes.

One particular application of the photomultiplier in astronomical work is the position control of large telescopes([62]). The problem is essentially that of guiding the axis of the telescope such that it remains directed towards one particular star or area of sky despite the earth's rotation which would produce misalignment if the telescope was not continuously corrected.

(11.3) Radiation detection

The photo-multiplier has been used to detect and measure the intensity of radiations from radio-active sources. Radiations such as alpha particles, electrons and gamma rays, produce fluorescent light in certain substances; moreover, when a particle or quantum strikes a fluorescent screen the conversion of the particle or quantum energy to light is almost complete, so that the intensity of the scintillation is a measure of the energy. A photo-multiplier can be used to detect single radiations, quanta or particles provided that the scintillation releases a number of photoelectrons greater than the number of 'dark-current' electrons emitted during the fluorescent response time of the screen. For example, 5 MeV alpha particles have been observed to release about 10^4 electrons each, and the amplitude of the amplified photo-electric current pulse when displayed on a cathode-ray tube is about 50 times background noise. Similarly, 1.7 MeV beta particles (electrons) give pulse heights of about 10 times background noise and single pulses from 25 kV X-ray quanta can be distinguished above noise. Measurements of corpuscular radiations and X-rays by photocells, and constructions of special tubes for detecting single particles have been described by several authors.

(11.4) Recording of transient optical phenomena

The photo-multiplier is particularly applicable to the recording of transient optical phenomena, such as electrical discharges, lightning and the light output from photo-flash tubes. The problem is essentially the presentation of the intensity variations of the source as a function of time on an oscillograph. The photo-multiplier is used for converting the optical transient to an electrical transient which can then be presented on the cathode-ray tube screen in a conventional manner. In many applications the transient is a single event, the duration of which may be between wide limits, 10^{-1} sec. down to 10^{-8} sec. Thus, the oscillographic techniques involved present numerous problems associated with trace intensity, writing speed and synchronization.

(11.5) Reflectometers, fluorometers, refractometers, colorimeters and turbidimeters

Photocells find many applications in the measurement of reflection and emission from, and transmission through, materials. Reflection may be measured by a reflectometer or goniophotometer. One reflectometer, described by Hunter([63]) measures specular reflection, diffuse reflection and their ratio for a fixed angle of incidence of 45 deg., and certain attachments enable the colour characteristics, transmission and sheen (specular reflection at large angles of incidence) to be determined. A precision goniophotometer designed to measure specular and diffuse reflectance at all angles has been described by Moon and Laurence([64]).

Ellinger and Holden([65]) have produced a simple fluorimeter for estimating the vitamin concentrations in solutions. In this device a high-pressure mercury arc emits two beams which are filtered to remove visible radiation and then one passes through the specimen under test, the other through a standard fluorescent substance. After passage through these materials the ultra-violet is removed and the visible radiation beams fall on two photocells connected in opposition and to a

galvanometer. The reading on the galvanometer is a measure of the concentration of the fluorescent material in the liquid. Similar more sensitive equipment has been developed for weakly fluorescing materials([66]). A closely related topic is the measurement of bacterial luminescence. Parker and Oser([67]) have determined the vitamin A content of liquids by measuring the absorption of radiation of 3280Å wavelength. Other vitamins can similarly be detected photo-electrically and the presence of vitamin A in cod-liver oil can be continuously controlled([68]). Photo-electric colorimetric methods can be applied to numerous other chemical problems, and a long list of references on the topic of photo-electric methods in analytical chemistry has been prepared by Muller([69]). Such methods have been used for determining colours of petroleum products and lubricating oils. Engine wear has been determined by measuring the iron content of oil with a photo-electric colorimeter([70]).

Turbidity, the presence of small particles of solid matter in liquid, can be measured by an arrangement in which the solid matter causes scattering of a light beam. A similar system has been applied to the measurement of the effectiveness of air filters where light scattered by the unfiltered air is made to fall on a photo-multiplier, and is compared with light scattered by filtered air. The fineness of cement has been measured by utilizing the scattering effect which the finely dispersed particles exercise on a light beam passing through a suspension of cement in castor oil or liquid paraffin. Sewage has been analysed and controlled by turbidity measurement. Turbidimeters have been used for measurements of penicillin and for observing the action of penicillin on staphylococci. Turbidimetry in the infra-red region has been discussed by Barnett([71]).

Photocells have also been used for observing films precipitated in the form of insoluble soaps on surfaces immersed in detergents, for measuring the scattering of monochromatic light as a function of the angle of scattering for solutions, for measuring small differences in refractive indices of liquids and for determining haemoglobin and chlorophyll contents of solutions. There are many other photo-electric devices which give indications of the presence of substances in air or liquids. The water-vapour content of the atmosphere can be determined, for example, because water vapour absorbs infra-red radiation of 9,340Å strongly. Poisonous gases can be detected by their strong absorption for certain ultra-violet lines. A similar method can be used for detecting large concentrations of carbon disulphide gas.

(11.6) Infra-red Equipment

Signals transmitted on infra-red beams can be detected with thallium-sulphide cells, or other photo-conductive cells, or by a photomultiplier or an image tube. Infra-red radiation of activated phosphors of ZnS, CdS, CdSe and CdTe causes changes in the dielectric constants of the materials and this phenomenon can be used as a sensitive indicator of infra-red illumination([72]).

Lead-sulphide photo-conductive cells are efficient detectors of hot bodies such as aircraft-engine exhausts and ships' funnels. They have also been used for detecting radiation from filament lamps for infra-red telephony, in pyrometry and infra-red spectrometers, for measuring temperatures resulting from severe braking in moving vehicles, for detecting hot axle-bearings, and for monitoring gas, oil-fired and pulverized fuel furnaces.

Often the detection of an infra-red-emitting object is not sufficient, as its shape must also be known. Image tubes can be used to convert infra-red images to visible ones. In the development of infra-red equipment, emphasis has been on military applications, but image tubes and infra-red telescopes can be used for detecting forgeries, infra-red microscopy, and for photographic purposes where visible light must be excluded. The Germans have produced devices such as the infra-red iconoscope([72]) extending the wavelength range much further than the image-tube range.

(11.7) Miscellaneous applications

Photo-electric equipment finds wide application in continuous automatic control of chemical and industrial processes in industry. They are used, for example, for smoke and dust detection, observing colour and gloss of fibres and materials in the textile industry, observing colour of flue gases, and as flame-failure detectors. Smoke detectors are used a great deal on ships and in the air-conditioning systems of theatres. Photocells for controlling high temperatures, smoke, etc., may be water-cooled. Uniform flow of liquid through a pipe can be maintained photo-electrically([73]). There are several photo-electric methods for speedily cutting metal sheet with blow torches from given patterns, controlling heavy machine tools, producing smooth-ended rolls in the paper industry, inspecting quality of machined surfaces, providing safety "curtains" for operators of machines, measuring thickness and width, determining the diameter and elastic properties of wire, and the uniformity and strength of yarn, and for checking piston rings.

Photo-electric devices are useful for supervising

automatic packing, and for automatic inspection such as testing eggs for freshness, examining fruit and vegetables for quality, colour and size, checking for foreign particles in bottled drinks or packaged goods, detecting chipped or cracked bottles, inspecting surfaces for cracks, flaws or impurities, checking goods for missing items, and the measurement of sugar content in beverages or concentration of syrups. Photocells find applications in automatic weighing and automatic sizing of spherical objects such as steel balls and oranges.

The effects of high-altitude flying on the oxygen content of the blood have been observed photo-electrically[74]. The illuminating lamp is fixed on one side of the ear and the amount of green light transmitted through the thin scapha membrane of the ear is measured by a photocell on the other side. Photo-electric guiding aids and reading aids have been produced for the blind.

Moisture content of steam can be determined by its transparency. Automatic chlorination of water can be based on the detection of residual chlorine by the yellow to orange-red discoloration of an orthotoluidine reagent[75]. Similarly, mercury vapour can be detected by the discoloration of selenium sulphide[76] and ozone can be detected because it absorbs radiation of 3,130A wavelength[77]. Water hardness and organic matter in sand filters for water purification can also be determined with the aid of photocells.

Other uses of photocells include automatic opening of doors and control of artificial lighting, counting of traffic, photography of fast-moving objects, railway signalling, burglar alarms, increasing accuracy of galvanometer readings, recording paths of vehicles, determination of correct locking position of the moving span of a road bridge over the River Forth, automatic titration, measuring delay in striking of fluorescent lamps, testing the output of high-frequency transmitters, measurement of cloud heights and cloud depths at various heights, transmission of television programmes over beams of light, pressure indication, firedamp detection and other mining applications, liquid-level and rate-of-flow[73] indicators, measurement of time intervals, voltage stabilization, measurements on Raman spectra for analysing hydrocarbon mixtures, measurement of vibration, pyrometry and photographic exposure. Photocells are also widely used in acoustics, for example in sound reproduction. Interesting acoustical applications are the light siren and photo-electric organ.

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Discussion

Mr. G. T. WINCH: I have listened with very great interest to Dr. Benson's presentation, and particularly I would like to congratulate him on his demonstrations. We all know what a tremendous amount of work is involved in preparing demonstrations such as these, and they have enabled us to see in practical form many of the applications he has referred to briefly in his paper.

This very broad survey paper is perhaps exceptional in the large number of references, extending to about half the length of the paper. The paper in general divides into two main sections, and shows on the one hand the applications to measurement (which I think is of special interest and of importance to illuminating engineers) and on the other many detection and allied applications.

In such a broad coverage, the author has, of necessity, only touched on the many aspects of the subject referred to, and I could have wished that he had spent more time on one or two selected items. I was glad to see he referred to fatigue effects in photocells. He has demonstrated that by light-chopping methods fatigue effects can be minimised. In some of the more precise measurement applications, however, one is driven to use D.C. methods of measurement in which photocell fatigue may prove an embarrassment. I would like to ask, therefore, whether the author has examined in detail the causes of fatigue and the methods of minimising fatigue. I have in mind precision measurement applications where, for example, it has been found desirable to maintain the cell at a constant temperature, and to choose specially designed cells in order to keep fatigue effects to a minimum. Could the author perhaps elaborate on fatigue and methods of minimising errors from this cause, because I feel that this is a field in which very useful work could be continued in the design of special photocells, particularly for D.C. light measurement.

I was glad that the author referred to the question of noise, on which I would like more

information, particularly with respect to photo-multipliers. I have in mind that sensitivity is expressed in microamps per lumen, often with little, if any, reference to limiting sensitivity. For example, one can sometimes obtain a higher threshold sensitivity with a single-stage photocell than one can with a photomultiplier, because of the smaller dark current in the former at room temperature. This, I think, needs particular emphasis, otherwise the advantages of photo-multipliers sometimes tend to become exaggerated.

I would like also to ask for some more information on some of the newer types of photoelectric devices referred to; in particular photo-transistors. Are we to understand that photo-transistors are only suitable for detecting applications, rather than measuring applications? They apparently have the potential advantage of very much greater sensitivity. Can we hope that these might be useful for precision measuring applications, or must we consider these only for detecting devices?

I would like to ask for more information on the new absorption edge converters which I found particularly interesting.

Dr. G. A. Veszi : Dr. Benson has covered a very wide field in a most admirable way. He, as well as Mr. Winch, mentioned the fatigue of photo-electric cells and I do not envy Dr. Benson if he is to reply to the questions raised in connection with this phenomenon. I think the expression " fatigue " is a rather terrible portmanteau-word, lumping together a large number of heterogeneous phenomena.

As a maker of selenium photo cells of the barrier layer type I would like to restrict my remarks on fatigue to this particular field. The complexity of the question is shown by the fact that even a well made cell will show a few per cent drop in output after a prolonged exposure to high intensity illumination if it is short-circuited during exposure. This is a reversible effect and its magnitude depends on the light intensity and the spectral characteristic of the fatiguing light. If the same cell is exposed in the same conditions, but open-circuited, the output will be found to have increased by a few per cent. This negative fatigue is again reversible and the cell recovers after a while its original properties.

Thus as a cell maker you observe the first effect with some dismay and the second with some relief, but the latter is only temporary because neither fatigue effect is really welcome. The essential requirement for a cell is reliability and stability. Fortunately, you can always choose a happy medium between the two extremes of short circuit (positive fatigue) and open circuit (negative fatigue) effect by choosing a suitable resistance value between zero and infinity and thus reducing the fatigue to practically nothing. Unfortunately, this measure has also its limitations as it will apply fully only to a limited range of illumination intensities. What matters is obviously the ratio of the fatiguing load resistance to the internal resistance of the cell and as the latter is inversely proportional to the illumination intensity a load resistance may be relatively large at a high intensity and relatively small at a low intensity of illumination.

Such are the ups and downs in the cell maker's life, but I am glad to say that by certain measures in the manufacture of selenium cells one can reduce the general fatigue of selenium cells very considerably as some work in progress at the moment indicates.

Dr. J. W. T. Walsh : I am a little concerned at the apparently great increase in the use of photo-multiplier cells for light measurement. What is the author's opinion about the relative merits of the photo-multiplier cell and the photo-emissive cell, apart from those cases where very low intensities have to be measured and the utmost sensitivity is needed? To secure good linearity one has to go to considerable lengths in the design of an ordinary photo-emissive cell and a lot of work has been done on that, particularly by Boutry. The photo-multiplier cell is very complicated, as compared with the ordinary cell, and I am wondering whether, in combination with this high sensitivity, it has proved possible to get satisfactory linearity.

There is another effect, too, I would like to ask Dr. Benson about. It is well known that, with the ordinary cell, if one has a very small spot of light incident on the cathode the sensitivity of the cell is liable to change as the spot is moved across the cathode. From the diagram of the photo-multiplier cell shown by Dr. Benson, it appeared to me that the construction and the arrangement of the dynodes might well increase this effect, and I would like to know whether Dr. Benson can tell us anything about this.

Mr. S. Anderson : I was interested in Dr. Benson's mention of the colour temperature meter amongst his many exhibits, and I gather that it makes use of the very simple arrangement of two cells, each with a colour filter in front of it, but I was also struck earlier in his paper with the " negative " characteristics of some of these photo-cells, when he showed on the graph that the cut-

off occurs at different points according to the wavelength or the colour of the light incident on the cell. Would it not be possible to make up a colour temperature meter based on this negative part of the characteristic, which I think would be a rather neater solution to the problem than the double cell and double filter which he has demonstrated.

Mr. A. W. S. TARRANT: I would like to ask Dr. Benson one question. He showed us a photograph of the zig-zag type of photo-multiplier. How do the electrons know which electrode to go to first? Perhaps I misread the diagram, but it seemed to me that the electrode marked 2 was nearer to the cathode, and they might therefore go to the wrong surface.

Mr. J. B. COLLINS: I would like to ask Dr. Benson if he could give us a few more particulars about the constant voltage piece of apparatus—in particular what the sensitivity of control is, what the speed of response to voltage variations is, and what are the effects of fatigue in the cell and ageing of the lamp?

Mr. R. R. HOLMES: With the portable type of light meter, it is quite frequently experienced that there is a slight uncertainty in the reading, and this is very often overcome by movement of the glass covering surface, below which is usually a collector-plate picking up from the top surface of the cell. I would like Dr. Benson to comment on whether he would expect slight disturbances of the collector-plate position to get rid of a contact resistance that was not there when the cell was first calibrated.

THE AUTHOR (in reply): Mr. Winch first asks for information on fatigue. I have briefly commented on this topic in the paper where I say that I think changes in sensitivity of a photo-emissive cell may be caused by changes of the delicate cathode surface, possibly due to electron emission or to impurities. A gas filled cell shows pronounced fatigue effects probably as a result of ion bombardment of the cathode, or liberation or adsorption of gas by the electrodes or envelope. If the surface layer of the cathode is damaged, the sensitivity of it will be reduced. Liberation or adsorption of gas will change the gas pressure slightly and so the amplification factor.

Much has been written on the subject of fatigue, but many of the observations are still not satisfactorily explained. It may be of interest, however, to add a little more to the information already given in the paper. Thick-layer photocathodes exhibit fatigue phenomena which are attributed to delayed refurnishing of electrons to ionised adsorbed atoms. This results in the reduction of the number of atoms which can be photo-ionised and the quanta magnitude necessary to ionise the remaining adsorbed atoms is increased. Long exposure therefore, causes the selective maximum to be less pronounced, and also to move towards shorter wavelengths. The insufficient supply of electrons results largely from the building up of a space charge in the interior of the oxide layer due to the electrons being trapped in the oxide lattice. This space charge screens the field from the base metal, preventing further electron emission. Electrons may be dislodged again by thermal motion of the lattice, so that eventually the charges are again neutralised. The process may be accelerated by heating or by radiation with infra-red illumination.

Another fatigue effect, which is pronounced with high electrode voltages, is a diminution of reponse with time, especially when using long wavelength light, caused by drift of adsorbed alkali ions to the base metal, under the influence of the applied field. After neutralisation at the base metal, the alkali atoms diffuse again towards the surface, and the original condition is restored.

The above effects are least for layers which contain large numbers of neutral metal atoms, and adsorbed caesium atoms.

I wish to thank Dr. Veszi for his interesting comments about fatigue in selenium barrier-layer cells. All cells of this type seem to exhibit temporary fatigue on exposure to light, which frequently increases with the intensity of illumination. The fatigue also varies considerably from cell to cell even of the same type, with the value of the external resistance, and with the wavelength of the light. Selenium cells seem to show greater fatigue than those of the copper-oxide type.

Hardy has obtained some very interesting results in considering problems connected with the use of sphere gaps for the measurement of voltage. ("The measurement of pre-breakdown currents in discharge gaps" by D. R. Hardy—Thesis submitted for the degree of M.Sc. University of London, May, 1948.) He studied the effect of photo-electric fatigue and the current flowing in the gap for various electrode and surface conditions, since it was believed that this would play as important a part on the breakdown of the gap as does the nature of the ultra-violet light which generally provides the radiation. The materials chosen for the tests, were brass, copper, steel and aluminium, since they are mainly used in electrod

construction. Also zinc, tin and magnesium because they produce appreciable photocurrents when irradiated with ultra-violet light. He found that the highest photocurrent was obtained from the zinc cathode. Tin and magnesium produced currents about one-fifth of the current from zinc. Photocurrents from the accepted electrode materials copper and brass, were less than one-half those for tin and magnesium. Aluminium was expected to produce larger currents than those recorded. The low value obtained was probably due to unsatisfactory surface conditions. Hardy concludes that the fatigue effects are largely due to oxidation.

Secondary emitting surfaces such as those used in photo-multipliers do not retain their initial multiplication ratios when bombarded continuously with electrons. The magnitude of this decay or fatigue depends largely on the current density, but is influenced also by the operating voltage. The multiplication generally drops rapidly at the start of a running period, then tends to remain constant at a lower value. If a period of running is followed by a resting period, where the applied voltage and radiation are removed, the sensitivity may recover to approximately its initial value. This fatigue effect, which again varies noticeably from tube to tube, is caused by a reduction in secondary emission ratio of a surface, and may be caused by removal of caesium from the material by electron bombardment, or by migration of positive ions inwards from the surface. When the absence of fatigue in photo-multipliers is very important, limits must be placed on the overall voltages and currents used for continuous operation.

I certainly agree with Mr. Winch that there is sometimes confusion between the sensitivity of a photocell in terms of microamps per lumen and its limiting sensivity, as he has previously pointed out. (" Recent developments in photometry and colorimetry " by G. T. Winch.—Trans. Illum. Eng. Soc. (London), **21**, 91 [1956]). It is the latter which is the important controlling factor when considering ultimate attainable sensitivities and when using the best amplifying means.

The limiting sensitivity depends not only on the microamps per lumen of the cell, but also on leakage and dark current, which control the noise and hence the minimum detectable signal. It was pointed out in the paper that dark current is due to thermionic emission from the cathode, and so depends on the form and spectral response of the cathode. This can be reduced by cooling the cell.

Incidentally, some interesting comments on dark current in photomultiplier tubes have been given in a paper by Sharpe (" Photomultiplier Tubes " by J. Sharpe, *British Communications and Electronics*, **4**, 484 [1957]). He says that because caesium has appreciable vapour pressure at room temperature, ionisation will occur in the output section of the tube, giving rise to both optical and ionic feedback, while stray electrons escaping from the dynodes, or produced from caesiated points, can cause fluorescence in the glass envelope, which in turn gives rise to photo-emission from the cathode. Therefore, the dark current is always higher than would be expected from the thermionic emission of the cathode, and the discrepancy increases as the gain is increased by raising the voltage applied to the tube. When measuring very low light levels, these facts must be borne in mind. Reduction of thermionic emission by cooling the tube will, in addition, reduce the feedback processes, so that considerable improvement in dark current can be obtained by this means.

As Mr. Winch himself has found, the highest limiting sensitivity may sometimes be obtained from photocells with very low microamps per lumen sensitivity. Even though some photomultiplier tubes have sensitivities of the order of 20 amps per lumen, their limiting sensitivity has frequently not been any better than a single photocell with its associated amplifier, because of their high dark currents. Thus, I agree with Mr. Winch that the advantages of photomultiplier tubes sometimes tend to become exaggerated, and I can quite understand Dr. Walsh's concern about the apparently great increase in the use of photomultipliers for light measurements.

The germanium photo-transistor demonstrated during the lecture has opened up new possibilities for compact, inexpensive light-operated devices. It is similar in form to a conventional low-power transistor, and is sufficiently sensitive to operate a normal 25 milliwatt relay direct. In common with other types of transistor, it has the advantages of small size, low power consumption, no pre-heating requirement, and very long potential life. The circuits in which it may be successfully used are extremely simple—they may amount to nothing more than a photo-transistor in series with a relay coil, and a D.C. supply of about 12 volts. In addition a photo-transistor has high sensitivity and high speed of response. The dark current at room temperature is less than 300 microamps, which is small compared to the light current of 5/10 milliamps. The spectral response has a peak in the infra-red region, but continues into the

visible light region. Light modulating frequencies up to 3 kc/s can be employed.

All transistors are, of course, relatively new devices, and at present there are fairly large variations in the characteristics, from sample to sample of a given type and particularly with temperature. Photo-transistors are not suitable for operation at ambient temperatures above 45°C. In reply to Mr. Winch's question therefore, I think it is unlikely that at present they will be employed for precision measurements, but they can be used for most industrial control applications.

The new thermal-image converter which I briefly discussed has been described in a recent paper by Harding, Hilsum and Northrop. ("A new thermal-image converter" by W. R. Harding, C. Hilsum and D. C. Northrop, S.E.R.L. Tech. Journal, **8,** 104 [1958]). The device relies on the temperature dependence of the absorption threshold in a semi-conductor. When a sample of suitable material is viewed by transmitted monochromatic light at a wavelength near the threshold, any temperature variations appear as differences in the transmitted intensity. If, therefore, a scene in which there are objects of various temperatures and emissivities, is focussed on the semi-conductor, a visible picture will result.

The particular converter described uses amorphous selenium metallised on one side, mounted in a vacuum at the focus of a parabolic mirror, and light from a sodium lamp is employed. Ways of achieving high sensitivity have been enumerated by the above authors in their paper. Objects with temperatures 15°C above ambient can be observed. The sensitivity limit is determined by the smallest contrast which the eye can detect. The time constant of the device is less than .5 sec., and exposures of 2 secs. are enough to photograph the image. For objects greater than 200°C the aperture of the mirror has to be reduced to avoid crystallisation of the selenium.

In reply to Dr. Walsh, I might remind him that a photo-multiplier needs a highly stabilised supply for consistent results, because the gain varies as a high power of the overall voltage (about the eighth power for an 11-stage tube).

There is very little knowledge of the departure from linearity of the response of photo-multipliers, over the range of illuminations involved in precise photometric and colorimetric applications. Mr. Winch, in the I.E.S. Transactions paper referred to above, does refer to some work carried out on R.C.A. photo-multipliers, where low dark currents were quoted and the linearity of response of the output was claimed to be within the experimental accuracy of 3 per cent in the range of anode current of 10^{-9}-10^{-3} amp. This corresponds approximately to light levels of about 10^{-10}-10^{-4} lumen. Preliminary measurements made by Mr. Winch of the linearity of a certain development type of R.C.A. photo-multiplier have shown that within the accuracy of the method of measurement used, namely about 2 per cent, the output of this particular photo-multiplier is linear over a 12/1 light ratio at a level of 10^{-9} lumen. It is still doubtful, however, whether such photo-multipliers would be suitable for applications where the linearity of the photocell has to be relied on to a high order of accuracy. Sharpe, in the paper already referred to, points out that the linearity of output current as a function of illumination of the cathode, is of great importance in most applications. He says that, excluding the very rare case in which a tube is used at such low gain, and therefore at such high illumination that photo-cathode resistance is significant, any deviation from linearity is largely due to space-charge effects at the collector, and the last and penultimate dynodes. According to Sharpe, it is usual to specify a peak current for which the output current does not depart from linearity by more than some factor (say 10 per cent) for a given inter-stage voltage. In comparison with the figures just given, one might consider Boutry's specially designed types of cell, in which I understand the departures from linearity are too small to be measured with certainty.

I agree with Dr. Walsh that in many photo-emissive cells the sensitivity may vary greatly from one part of the cathode to another, and this is an important consideration when the illumination of the cathode is uneven—for example, when the beam of radiation has a cross-section smaller than the cathode. Similar variations will be present on photo-multiplier tube cathodes, and certainly at the dynodes where they are likely to be more troublesome. On the other hand electrodes in photo-multipliers are of rather small area, this being a disadvantage of the zig-zag type of photo-multiplier, illustrated during the lecture, because dynode 9 and the anode can very easily become over-heated by bombardment.

I was very interested in Mr. Anderson's comments about colour temperature meters. In the model exhibited, two cells were arranged in a balanced circuit with a centre zero galvanometer. One cell was fitted with a red glass and the other with a blue glass filter, and a shutter was arranged so that when it was rotated part of one cell filter combination got progressively obscured, while the other got progressively exposed to light. To measure colour temperature the shutter is rotated

t give zero deflection on the galvanometer, and th n the calibrated scale on the shutter gives the co our temperature. A somewhat similar arrangement has often been used in the laboratory, where the source is placed in an integrating sphere. Two windows are provided in the sphere and the light flux through them is received by a red sensitive and a blue sensitive photocell respectively. The ratio of the photocurrents may be employed to determine the colour temperature of the source. The ratio of their photocurrents is most conveniently measured by a null method using a Wheatstone bridge, with the two cells in two of the arms. I agree with Mr. Anderson that in theory it should be possible to make up a colour temperature meter, based on the negative part of the anode voltage/anode current characteristic, but as far as I am aware, such a device has never been described. I am not convinced, however, that it would be a very much simpler arrangement. It would, first of all, need a power supply.

In reply to Mr. Tarrant, I should like to draw his attention to the interesting results obtained by Rajchman, who in 1938 published a comprehensive study of the development of electrostatic types of photo-multiplier. Rajchman studied various electrode shapes, and these were sufficiently long in a direction at right angles to the electron paths, that a potential distribution could be considered to vary in two dimensions only. The potential distribution and the resultant trajectories could therefore be investigated by means of the well-known rubber drum model as pointed out in the paper. It is possible to use this method for two-dimensional problems, because of the relationship which exists between the potential distribution satisfying, in the absence of space charge, Laplace's equation $d_2V/dx^2+d_2V/dy^2=0$, and the height distribution h over the surface of a stretched membrane distorted by boundary "electrodes" $d_2h/dx^2+d_2h/dy^2=0$. If the datum level representing zero h is taken to be the level of a horizontal drum, an electrode shape which represents an electrode at say $V=100V$ should be arranged to depress the height of the membrane by 100 units. Trajectories can be obtained on the membrane by releasing a small ball, and allowing it to roll over the membrane from one electrode to another electrode, which is, for example, more depressed and therefore represents a more positive potential. These trajectories are geometrically similar to the true electron trajectories. In just the same way, in the zig-zag arrangement described, photo-electrons from the cathode are guided by the electrostatic field to fall on the first dynode from which after amplification the secondary electrons pass to the second dynode and so on round the tube.

The stabilised D.C. light source referred to by Mr. Collins employs an oscillator operating at about 3 kc/s, which feeds a power amplifier whose output is fed to the 6V, 48-watt lamp by a matching transformer. The lamp is monitored by a photocell, which detects variations in brilliance, these being fed back to the oscillator for control purposes via a servo amplifier.

For a change in mains voltage of $\pm$ 8 per cent the output voltage of this equipment varies by about +0.6 per cent to − 1.2 per cent. The stability of a heated filament undergoes short-period changes of considerable amounts due to, amongst other things, local thermal spots which persist for a short time and then stabilise themselves. Since, in this case, the filament is being monitored directly by the photocell, all such changes are immediately taken into account by the feedback system. The result is that no detectable drift is observed over 5- or 10-minute periods, or even over longer periods such as 8 hours. The effects of cell fatigue could be compensated for by adjusting the servo amplifier. I have no figures for the speed of response to voltage variations.

Other suitable ways of providing a D.C. supply for running a lamp at constant brilliance are to use a battery or a constant-voltage transformer. Both these have disadvantages. For example, if large currents are being drawn a number of batteries have to be used, and they need careful maintenance while the output voltage of most constant-voltage transformers is very dependent on mains frequency.

I was interested to hear about Mr. Holmes' experiences with portable-type light meters. I regret that I have no information on the effect of slight movement of the position of the collector plate on contact resistance.

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Lighting at the Brussels 1958 Exhibition

By ANDRE BOEREBOOM, I.C.C., I.E., A.I.G. *(Member)*

Summary

The lighting of an exhibition such as the Brussels 1958 Exhibition is a considerable undertaking. This paper gives a general outline of the problems of electricity supply and gives some details of the lighting of outside areas, the interiors of a few of the many pavilions and of the various water features and fountains.

The Universal and International Exhibition of Brussels, 1958, opened on April 17. The site of the exhibition is at Heysel, where a similar exhibition was held in 1935. The area covered by the present exhibition has, however, been extended by some 50 per cent. by incorporating part of the Royal Park of Laeken, the total area of the exhibition being 200 hectares (nearly 500 acres).

Situated only a few kilometres from the centre of Brussels, the Heysel site is well suited for this type of event, being easily reached by car or by public transport and with ample car-parking facilities.

The exhibition is divided into several sections. The Grands Palais section comprises the permanent buildings remaining from the 1935 exhibition which have been refurbished and in some cases enlarged. The Belgian section shows the country's technical and industrial achievements and is separated from the foreign section by Osseghem Park, where foot-weary visitors may take their ease. In the foreign section 53 countries are taking part. There is also a section devoted to the Belgian Congo and a further section in which the various international organisations are exhibiting. Finally, there is the Belgian Folklore section called "Gay Belgium," and the amusement section which must inevitably find a place in an exhibition of such a size.

Throughout the exhibition the lighting of buildings, pavilions, parks, gardens, and fountains plays a very important part. Lighting can give such an event a characteristic atmosphere and, indeed, enables technicians and designers to display their skill. The techniques used in an exhibition such as this represent the *avant garde* and give inspiration for several years to come. This is certainly true of architecture and is probably true of lighting.

The first section of this paper deals with the supply of electricity to the exhibition; the second part describes the exterior and interior lighting, and the third part describes some of the illuminated fountains.

The author is with the Ministry of Public Works, Brussels. The manuscript of this paper was first received on February 14, 1958. The paper was presented at a meeting of the Society in Eastbourne on May 13, 1958.

(1) Electrical Distribution Systems

(1.1) General

The total capacity of the electrical installations exceeds 60,000 kW. To determine the capacity to be actually provided presented difficulty because at the time when the supply system had to be planned and work commenced the electricity requirements were not known. Taking as a basis the experience of the 1935 Exhibition, and subsequent exhibitions, a total installed output of 40,000 kW was contemplated at the beginning of 1955. However, as demands were received it was found that the estimates had to be reviewed, and therefore in the middle of 1956 a total installed output of 50,000 kW had to be provided. Again, only a few months before the opening it was found necessary to extend to 60,000 kW.

The experience of 1935 had also shown that the maximum quarter-hourly load was approximately half the total transformer installed capacity. The system was therefore calculated for a maximum quarter-hourly output of 25,000 kW but capable of taking an additional demand of 20 per cent.

Power is obtained from the thermal power station at Interbrabant situated 4 km. from the exhibition, and the characteristics of the supply are 11,000 volt, 3-phase, 50 cycle.

The high-tension mains comprise :

(*a*) a primary system feeding the various distribution cabins and transformers ;

(*b*) a secondary system feeding the different consumers with high tension.

There are in addition three 220-volt low-tension networks :—

(*a*) The general main.

(*b*) The public lighting main.

(*c*) The emergency main.

The characteristic of the distribution of electricity is that approximately 90 per cent. of the output is supplied at high tension. Only a few

small consumers with connected loads less than 1 kW are connected to the low-tension network.

(1.2) Primary high-tension system

A primary high-tension system is supplied from the Interbrabant Power Station by eight armoured cables, 3 core, 185 sq. mm. in section, which terminate at two cabins, four cables to each cabin. A cable loop of the same dimensions connects the different cabins of this system. The total length of high-tension cable exceeds 50 km.

Each cabin of the primary system is fitted with two or three transformers of 400 kVA capacity at 11,000 volts incoming and 220 volts outgoing supply. The use of 400 kVA transformers was deemed to be the most suitable, as this type can be readily used on other networks after closure of the exhibition.

The proximity of the Interbrabant Station to the exhibition called for the provision at each intake of a 3-phase induction coil, reducing the cut-out power from 800 MVA to 250 MVA ; this to make it possible for consumers to use throughout the system 250 MVA cut-outs of normal design.

The assembly of indirect relays provides for the directional protection of the feeders of the Interbrabant, and differential longitudinal protection is provided on the loop connecting each of the cabins of this primary system. Finally, a maximum protection is provided on the different high-tension outputs of the primary cabins.

The equipment of the cabins on the primary system is of the " Hall " type.

(1.3) Secondary H.T. mains

The secondary H.T. mains comprise a series of 11,000 volt, 3-core cables, 70 sq. mm. in section, connecting the different high-tension consumers to the primary cabins. These consumers are in general connected to a loop joining two primary cabins and the loop is carried out in such a way that in principle all the consumers of one loop can be supplied from either primary cabin. In practice, however, a break is made on the secondary loop so as to distribute the loads over the different cabins of the primary supply and on the two main intakes.

The number of secondary high-tension consumers is 103, and the output of the transformer cabins varies from 50 to 3,000 kVA. The total length of 3-core cable (70 sq. mm.) is 25,850 metres.

(1.4) Low-tension system

The low-tension system of 220 volts is fed from the primary system cabins and serves the motive power and lighting installations in the various public buildings. A low-tension system is designed specially for public lighting. This system is switched on in the evening and is cut-out at midnight, contact clocks being provided for this purpose in the transformer cabins.

There is finally an emergency system supplied by a diesel unit which is automatically switched on in the event of a current failure in the main system. The diesel unit has an ouput of 400 kW, of which 300 kW is for the emergency system of the exhibition and 100 kW is set aside for the electrical installations of the Atomium. This system feeds certain lamps of the public lighting system. It should be noted that the lamps connected to the emergency system are lit at the same time as the other lamps of the public lighting system and remain in operation after the normal closing time of the exhibition (midnight) to permit of watchmen's rounds ; normally this emergency system is connected to the public lighting system but in the event of a breakdown in the latter the diesel unit is switched on and then feeds the emergency system. The time for automatic switching on does not exceed 25 seconds.

The magnitude of the distribution system is obvious from the following data :—

Primary High-Tension Mains	3 core, 185 sq. mm. sectional area, 50 km.
Secondary A. C. Mains	3 core, 70 sq. mm. sectional area, 26 km.
Low-Tension Systems	(*a*) 3 core, 120 sq. mm. sectional area, 26 km.
	(*b*) 3 core, 70 sq. mm. sectional area, 24 km.
	(*c*) 3 core, 35 sq. mm. sectional area, 2 km.

To the above can be added more than 16 km. of smaller and less important cable.

(2) Outside Lighting

(2.1) General lighting

It was agreed in principle that the general lighting of the exhibition should be effected by the pavilions themselves, which constitute the centre of attraction and must therefore be brightly lit after dark. Part of this lighting is of necessity reflected on to the roadways and assists movement of traffic over a large part of them.

Where the pavilions are too far apart, special lighting must nevertheless be provided. Considerable thought has been given to this and numerous ideas have been put forward and tested : luminous "ceilings," illuminated sculptures, acrylic obelisks, low elongated fittings, etc. None of these, however, was adopted for it was important, in the opinion of the architects of the exhibition, not to encumber

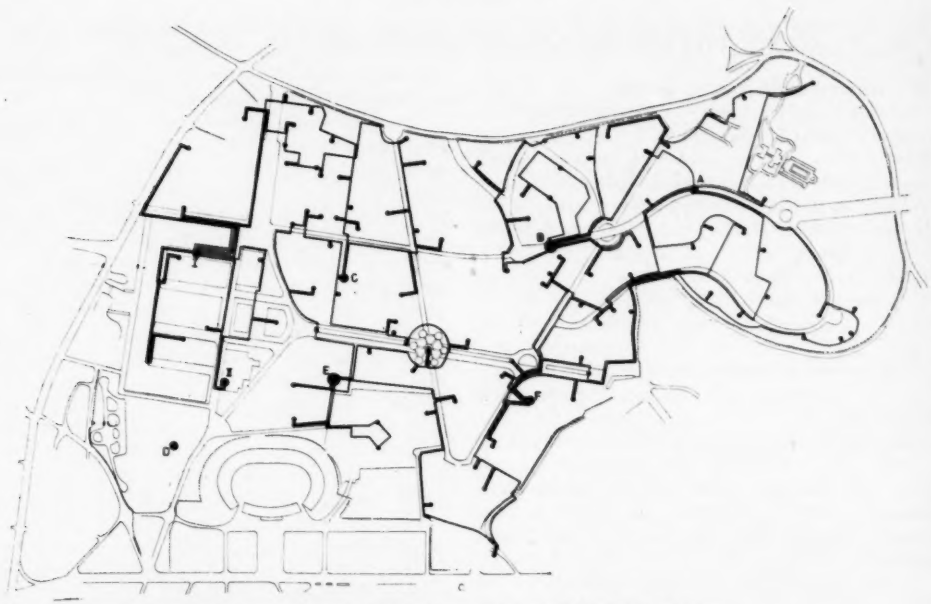


Fig. 1. Showing layout of secondary 11,000-volt supply mains from the primary H.T. cabins (A-F) to the secondary H.T. cabins.

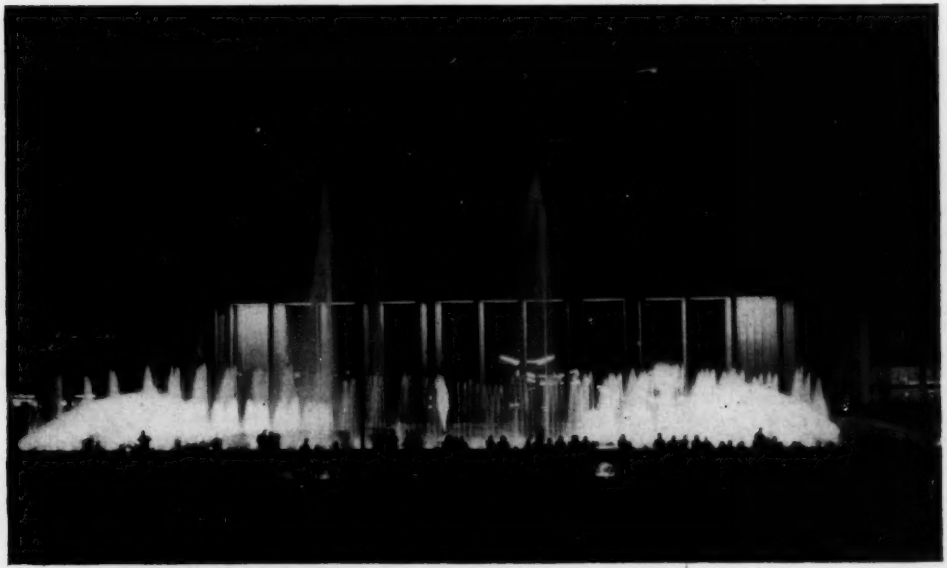


Fig. 2. View at night from the Reception Hall across the Water Buffet to the Atomium.

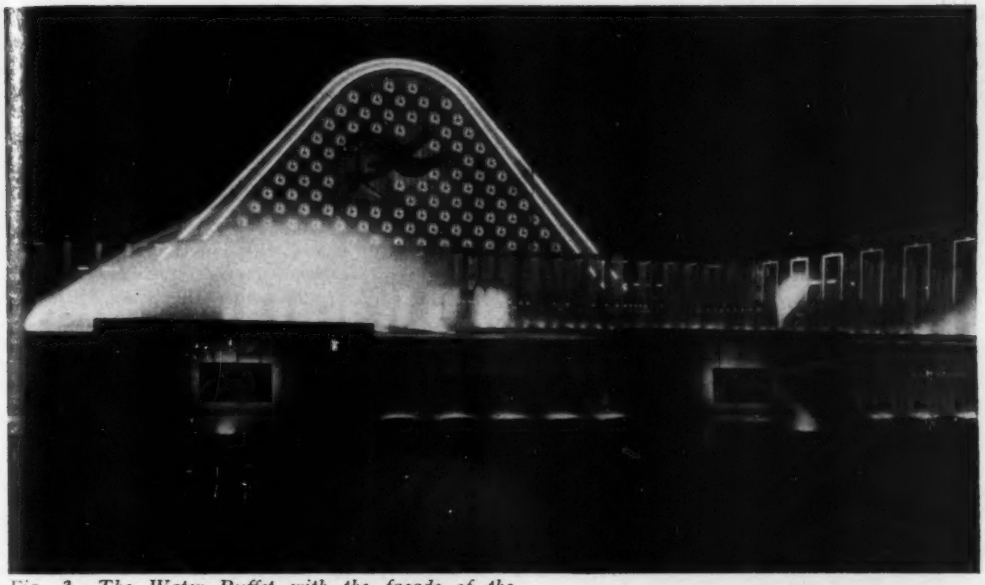


Fig. 3. The Water Buffet with the facade of the Reception Hall seen also in Fig. 4 (right) which shows the arches in the Place de Belgique.

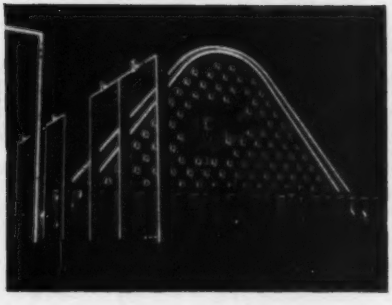
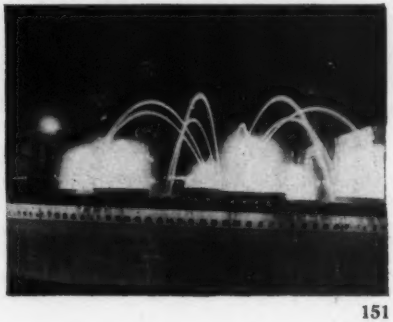


Fig. 5 (left). The Atomium.

Fig. 6 (below). The Benelux Fountain.



the roads and not to interfere with the view of the pavilions. Eventually a fitting made of formed extruded cellulose acetate was adopted ; it houses six 40-watt tungsten filament lamps and is mounted on a 4-metre galvanised metal post finished in the same colour as the motif on top of the fitting. The posts are normally spaced at 20 metres apart.

In other places, and in particular in the wooded parts, lighting is provided by projectors lighting the mass of greenery. Glare is avoided by placing the projectors in concrete pipes buried in the ground, or by fitting screens or louvres. Depth and relief effects are obtained by placing certain projectors behind the trees so as to cause their silhouette to appear against a background of light. The lamps used vary from 150- to 1,000-watt and are generally incandescent, though in certain places use is made of 400-watt colour-corrected mercury lamps or 140-watt sodium lamps. Certain concentrated beam projectors are fitted with 1,000-watt lamps supplied at 24 volts.

(2.2) Lighting of the Belgian section

Part of the Belgian section is lit by means of 12 prestressed concrete 30-metre-high columns, in order to keep the number of supports to a minimum. Each column is fitted with a four-leafed-clover-type fitting, each leaf of which houses three 1,000-watt mercury lamps and one 1,000-watt tungsten lamp ; the total light output per fitting exceeds 700,000 lumens. Columns are spaced 125 metres apart and the illumination on the road is between 7 and 65 lux. To reduce glare, black aluminium louvres are used. Control gear is housed in a container near the foot of each column.

(2.3) Lighting of the Place de Belgique

The visitor arriving at the exhibition through the Grands Palais entrance passes through the reception hall on to the Place de Belgique, from which he has a general view of the whole exhibition. This Place is lit by the facade of the reception hall, a series of arches on three sides of the square, and by two special star-shaped fittings.

The facade is in the form of a parabolic arch 50 metres high by 100 metres wide at the base, faced with wood and painted pale blue. The central motif of the facade is a large replica of the exhibition symbol and a dove ; these, together with 100 smaller versions of the emblem, are lit from behind by cold cathode fluorescent tubing (18 mm, 100 mA) to show them by silhouette at night. Nine narrow-beam 1,000-watt projectors light the central motif from the front. The arch itself is silhouetted by four rows of fluorescent tubes (25 mm., 250 mA) on each side of the arch. The colonnade is lit by fluorescent tubes (38 mm., 800 mA) let into the columns and ceiling.

The arches of the lateral colonnades are 10 metres high and 5 metres wide. Each of the columns is fitted on both sides with an aluminium reflector and a single line of cold cathode tubing (25 mm., 250 mA). The cross-members house fluorescent tubes and are covered with coloured acrylic sheet.

On either side of the square there is a large star-shaped fitting mounted at a height of 12 metres, each of the five points being 12 metres long and housing five lines of fluorescent tubes (25 mm,, 250 mA).

The lighting of the Place Belgique is completed by a series of flat-type fittings around the water and the illuminated fountain of the Buffet d'Eau. The total lighting load (excluding the Buffet d'Eau) is 250 kVA.

(2.4) Lighting of Osseghem Park

Osseghem Park is the dividing line between the foreign section and the Belgian section ; it provides a corner where visitors may relax awhile, and therefore called for special lighting. The park is divided into three parts, each of which represents one of the seasons, spring, summer and autumn. The three seasons are differentiated by means of special lighting motifs in cold cathode tubing, green tubing being used for spring, yellow for summer and red for autumn.

In addition to the seasonal motifs the general lighting of the park takes the form of cold cathode tubing wound in very tight spirals.

(2.5) Lighting of the footbridge

Connecting the Royal Park of Laeken with Osseghem Park and passing through the foreign section at a height of 17 metres is a prestressed concrete bridge supported on concrete arches spaced at 25 metres. It comprises two 6-metre traffic lanes separated by a 10-metre opening with connecting transverse bridges at intervals.

Lighting is by means of 17 double fittings in the shape of the exhibition emblem ; each is 4.25 metres high with the upper point 10 metres above the footpath. The fittings are mounted in pairs in the same plane and are made of a framework of steel section with edges of polished aluminium filled in with fine mesh expanded aluminium ; the depth of the fitting is 40 cm. The fittings are mounted on metal tubes and guyed to the footbridge by steel cables covered with " Perlon." Each face of the fitting is edged with cold cathode tubing (25 mm., 250 mA) and one arm of the star houses a 125-watt

colour-corrected mercury lamp in a reflector giving direct light on to the footpath and a 150-watt tungsten lamp connected to an emergency supply. The total load per fitting (both faces) is 3.3 kW.

The underside of the bridge is fitted with 84 street lighting lanterns housing 500-watt tungsten lamps; there are also 20 100-watt lamps for emergency lighting.

(2.6) The Congo section

The special nature of this area is emphasised by the exterior lighting columns, of which there are 24 in all. These consist of a 6-metre high column made of angle iron, sheet metal and translucent acrylic sheet. The translucent side "windows" are lit by means of white de luxe 25-mm. cold cathode tubing operating at 250 mA; the translucent white moulded horns each accommodate a 3.40 m length of similar tubing.

(2.7) Lighting of flowers

The lighting of flower beds was not made any easier by the decision to find something more original than the widely used mushroom type fittings. Fluorescent lighting was excluded because of the inevitable size of the fittings.

The fitting chosen consists of a 1-metre vertical steel rod terminating in a metal sphere to which two, three or four anodised aluminium reflectors may be fitted and which may be turned in any desired direction. The rims of the spotlights have been given anti-reflection treatment which with the neutral grey-green finish of the whole ensemble renders the fittings inconspicuous by night and by day. Each spotlight houses a 60-watt tungsten lamp.

Another device used for garden lighting consists of 32-watt circular hot cathode fluorescent lamp placed on a base supporting a metal container to hold a flower pot, the whole being surrounded by a formed extruded cellulose acetate fitting. These fittings give sufficient light for people to walk around the gardens.

Where lighting in the parks is mainly by projectors lighting the trees, beacon lighting of the paths is provided. Two types of beacon are used. The first is an application of "piped" light and consists of a stick of clear acrylic plastic 66 cm. high and 40 mm. in diameter, machined to give a large number of diamond-shaped facets and sealed into a cast-iron box housing a 25-watt 24-volt lamp and an alumium reflector. The other type uses a 60-watt tungsten lamp in a formed extruded cellulose acetate enclosure.

(2.8) Place de la Cooperation Mondiale

The Place de la Cooperation Mondiale (100m × 70m) is lit by a luminous obelisk made of four angle members braced diagonally and mounted on a square concrete base. The obelisk is lit by 600 metres of cold cathode tubing placed behind horizontal aluminium shutters which are indirectly lighted.

(2.9) The Atomium

The Atomium symbolises an elementary cubic iron crystal enlarged 150 million times. It comprises nine 18-metre diameter spheres connected by 3-metre diameter tubes. Its total height is 110 metres and it contains 2,000 tons of steel. The spheres are covered with polished aluminium plates.

Being convex in shape the spheres reflect a very wide field to an observer and at night give a scintillating and colourful effect. In addition to reflected light each of the spheres itself emits light from 320 10-watt lamps which are distributed in nine circles on the surface of each sphere representing the trajectories of peripheral electrons. The lamps, with polished aluminium reflectors, are hermetically sealed behind glass covers in the surface of the spheres. By means of controllers, synchronised to a variable frequency system, these lamps light up and are extinguished to a prearranged sequence.

(3) Lighting of the Pavilions

The interior lighting of the various national pavilions shows great diversity, though the following general trends are apparent:—

(a) Wide use of spotlights, both flush and surface mounted, usually fitted with 100 or 150-watt lamps:

(b) The use of 100-watt 24 volt lamps for the lighting of interior panels;

(c) Large scale use of fluorescent lamps—usually concealed behind louvres or diffusing panels;

(d) The majority of hot cathode fluorescent lamps used are 40-watt warm white de luxe (4,200 deg. K) lamps. (A notable exception is the U.S.S.R. Pavilion where wide use is made of 125-watt fluorescent lamps.)

(e) As the facades of most of the pavilions are almost entirely of glass the interior lighting of the pavilions contributes to the exterior areas. Two exceptions to this are the Reception Hall, which is described elsewhere in this paper, and the Palace of Electrical Energy. The lighting in the latter building is provided almost entirely by that provided for the separate exhibits; the facade is covered by a large display of cold cathode tubing.

It is not possible in this paper to give details of

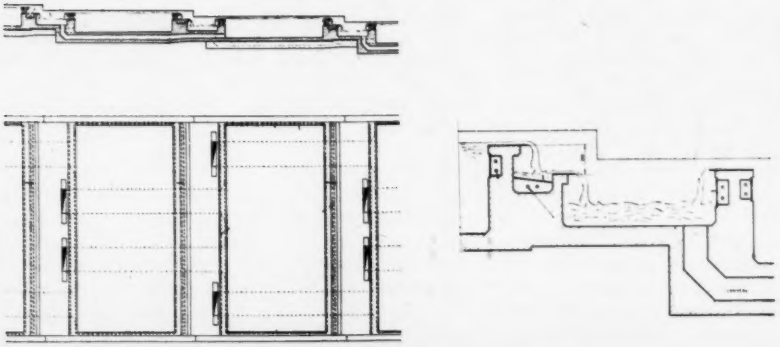


Fig. 7. Section and plan of part of the Water Ladder with (right) detail of one of the fall basins showing the position of cold cathode tubing.

Fig. 8. The illuminated exhibition emblems lighting the footbridge the underside of which is shown in Fig. 9 (below, left).

Fig. 10 (right). Showing the 30-metre columns used to light parts of the Belgian section.

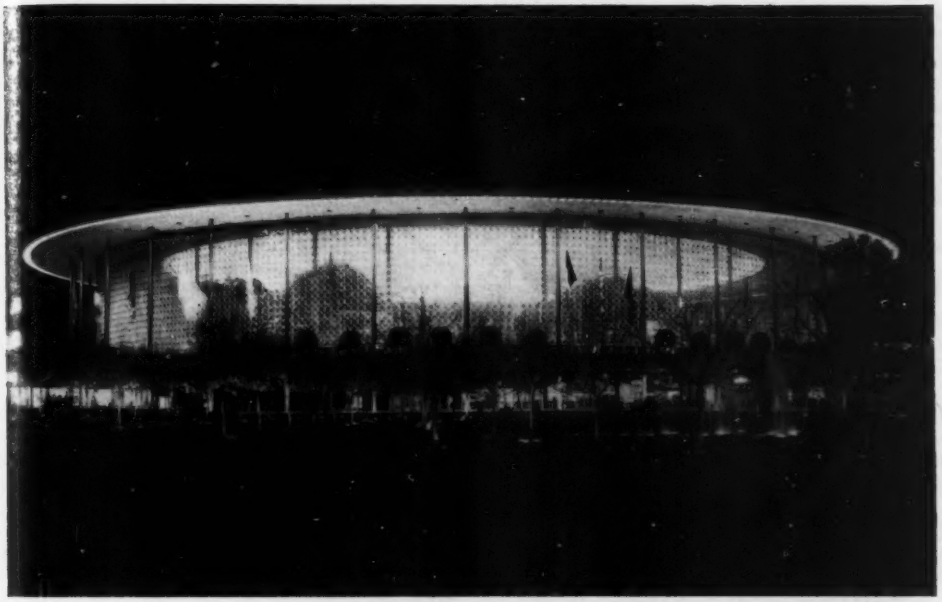


Fig. 11. The U.S.A. pavilion.

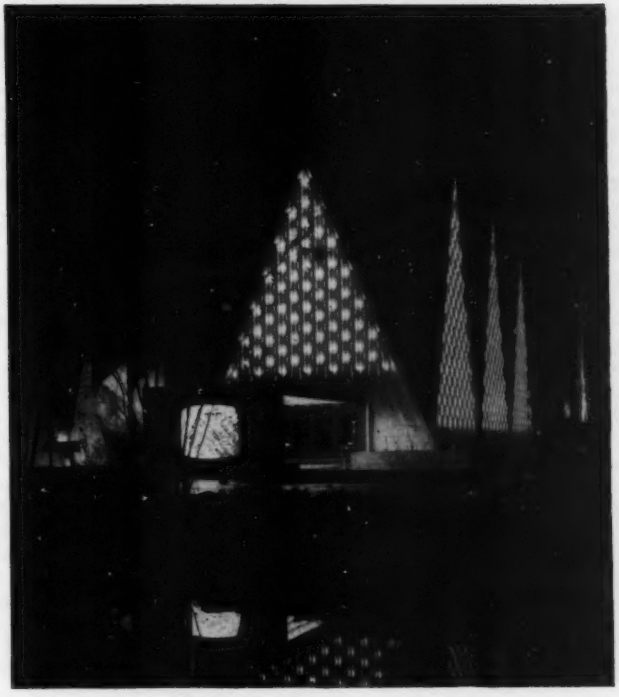


Fig. 12. The British Government pavilion.

the lighting of all the numerous pavilions but the following brief details are given of the more interesting features.

(3.1) The Reception Hall

The Reception Hall was one of the original pavilions erected for the 1935 exhibition. For the present exhibition however it has been completely transformed by concealing the girders of the original building behind a parabolic vault which is 30 metres high by 86 metres wide at the base. The hall is 160 metres long.

Entirely indirect lighting is used. Two troughs running the whole length of the building are suspended 9 metres above the floor by means of steel cables attached to the main girders. Each of the troughs contains 136 1,000-watt projectors spaced 0.80 metres apart; these light the upper part of the vault. The lower part of the walls is lit by means of 300-watt projectors placed on the structures provided inside the hall. The average level of illumination thus provided on the floor is 250 lux.

A number of indoor gardens at the sides of the hall are lit by 150-watt spotlights.

The total lighting load is 660 kW.

(3.2) Palais VII

The Palais VII is a new addition to the Grands Palais block. It is 160 metres long, 70 metres wide and 15 metres high. The frame of the building consists of 7 steel girders spaced at 24 metres apart. There is an entrance hall having a ceiling height of 16 metres and there are various rooms in the basement including an auditorium with a seating capacity of 600.

Natural lighting of the main hall is by means of roof-lights 4 metres square. Artificial lighting is provided by groups of four 40-watt fluorescent tubes in white-enamelled steel reflectors mounted direct to the ceiling in the spaces not taken up by roof-lights. The control gear for these lamps is mounted above the reflectors.

In the wings on either side of the main hall similar lamps in groups of 12 are fixed to the ceiling at right angles to the main axis of the hall. The entrance hall is lit by three continuous lines of 2 x 125-watt fluorescent lamps placed under the main girders.

The average illumination level is 250 lux. The total lighting load is 200 kW and is made up by 3,312 40-watt lamps and 210 125-watt lamps.

(3.3) Palais XI

Palais XI, like Palais VII, is a new and permanent addition to buildings comprising the Grands Palais group. It is 450 metres long, 40 metres wide and 10.5 metres high. It consists of two parts each 200 metres long separated by a central patio measuring 50 x 40 metres.

A large proportion of the ceiling area in each of the two parts is taken up by large double glazed roof-lights which stretch almost the full width of the building. Artificial lighting is provided by continuous fittings fixed to the transverse edges of the roof-lights, each fitting containing three continuous lines of 40-watt fluorescent lamps. The fittings are closed by striped glass and access for maintenance is obtained through the false ceiling.

The far end of each wing is lit by 109 spotlights housing 500-watt tungsten lamps. Similar spotlights are also used in the patio. The facade is lit by eight Infranor projectors using 3 kW tungsten lamps.

The average illumination in the interior is 300 lux and the total lighting load is 430 kW.

(3.4) The U.S.A. Pavilion

The U.S.A. Pavilion is a circular building having a diameter of over 100 metres and a height of 18 metres and is lit entirely by means of tungsten lamps. The ceiling consists of a vast circular area of acrylic sheet beneath which are mounted 1,600 150-watt reflector spot-lamps which shine down through a fine mesh false ceiling to give an effect as of daylight. The false ceiling is also lit from below by a further 432 similar lamps which are concealed in the inner crown of the structural circular ceiling and close to the false ceiling to give it a brilliant appearance. The central part of the ceiling is also lit by 360 projectors fitted with 300-watt reflectors spot-lamps.

The exterior of the circular ceiling is fitted with 432 150-watt reflector spot-lamps to light the acrylic walls.

The average level of illumination in the pavilion is approximately 200 lux. The total lighting load is 2,000 kW. It is interesting to note that the entire lighting of the U.S.A. pavilion is by tungsten lamps giving a warm colour.

(3.5) The U.S.S.R. Pavilion

The U.S.S.R. Pavilion is a vast building 160 metres long by 80 metres wide. A huge sky-light admits daylight to the interior; in this space there are also 385 open enamelled reflectors each housing four 40-watt fluorescent lamps. In addition there are 1,350 bare 125-watt fluorescent lamps fixed on to the ceiling. Lighting of tapestries and pictures on the walls is by means of 1,000-watt projectors. The average illumination

level is 350 lux increasing to 500 lux in the entrance hall.

(3.6) The British Pavilions

There are two British Pavilions, one being the official British Government Pavilion devoted to culture, science and the arts, and the other being the British Industries Pavilion in which is exhibited a comprehensive range of British products.

(a) The Government Pavilion

Considerable thought has been given to the external lighting of the three crystals forming the most prominent feature of the pavilion. The five most important triangular face panels have been fitted with embellishments in which are mounted well over 4,000 15-watt pigmy lamps, coloured to design in blue-green and white to form a most attractive show-piece which will be seen from the most important public thoroughfares in the exhibition grounds. The tops of the 70-ft. spires are floodlit from 1000-watt pageant spots, giving a delicate green effect and emphasising the clean-cut lines and imposing height of these crystals. The main entrance canopy soffit is formed in a total of 108 square panels each having a 100-watt lamp behind a tudor rose and green acrylic panel.

The V.I.P. Pavilion is also floodlit in a delicate shade of green from mirror reflector lamp units located at the base.

Pressed-glass weather-resisting 150-watt reflector spot-lamps are widely used for floodlighting individual features.

The internal lighting of the Government Pavilion comprises general and safety lighting to a minimum illumination level, with concentrated high level lighting to display a joint exercise between the co-ordinating architects and the display designers. Inside each of the three crystals is fitted a 26-ft. suspension 17-light electrolier fitted with 60-watt daylight blue lamps behind various colour cylindrical cinamoid shades, giving a sparkle effect on the purple-faced fluted panels to the crystals and demonstrating the considerable height of the crystals to the public entering the pavilion. Picture spotlights of low voltage high intensity are provided at high level with cut-off masks to evenly illuminate the broad stairs on both systems of lighting, at the south end of the crystals. Display features have their own lighting arrangements, part in tungsten mirror reflectors, part in hot cathode fluorescent, and part in ultra-violet lighting.

An interesting feature in the V.I.P. Pavilion is the method of general illumination, which is from a concealed theatre spot unit mounted on the floor under the circular table projecting its light through a centre glazed opening on to a reflector supported from the crystal structure.

(b) The Industry Pavilion

The British Industry Pavilion is designed as a glass showcase occupying 60,000 square feet and is of a unique design, the roof being supported by six central columns, the walls being constructed entirely of glass.

One of the features of the pavilion is the tracery of steel work on the roof and to allow this to be shown to the best advantage the general lighting consists of indirect lighting troughs housing 8-ft., 5-ft., and 4-ft. fluorescent warm white tubes. The lighting troughs are built up in four squares around each column, making 24 squares in all. The total length of troughing used is 3,600 ft., the connected load of the lighting being 50 kW.

The external lighting is a combination of the soft floodlighting of the trees and flagpoles, together with a number of street lighting columns in the shop area, and various low level lighting fittings on the steps and pathways.

The Vertical Feature consists of a single column 112 ft. high and it is illuminated at each of the four intermediate rings with three 150-watt weatherproof internally-silvered tungsten spot-lamps. The top cone is illuminated by nine 5-ft. 80-watt green fluorescent tubes.

One of the principal features on the British Industry Pavilion is the large neon sign "BRITISH INDUSTRY." This sign is 64 ft. long by 5 ft. high and consists of 3-ft. fabricated steel letters with white opal acrylic fronts illuminated from behind with cold cathode tubing, the letters being mounted on a sheet steel panel.

The largest part of the electrical load consists of the lighting of the exhibition stands within the pavilion and the total connected load of this exceeds 800 kVA. Lighting is a feature of every stand and the lighting load averages 15 watts per square foot of stand space.

(4) Illuminated Fountains

(4.1) Illuminated fountains are installed at different places in the exhibition. Some are of the classic type, such as those of Belvedere, Osseghem Park and Benelux Gate. Others have special characteristics which are described below.

Table I gives some information concerning the principal fountains installed.

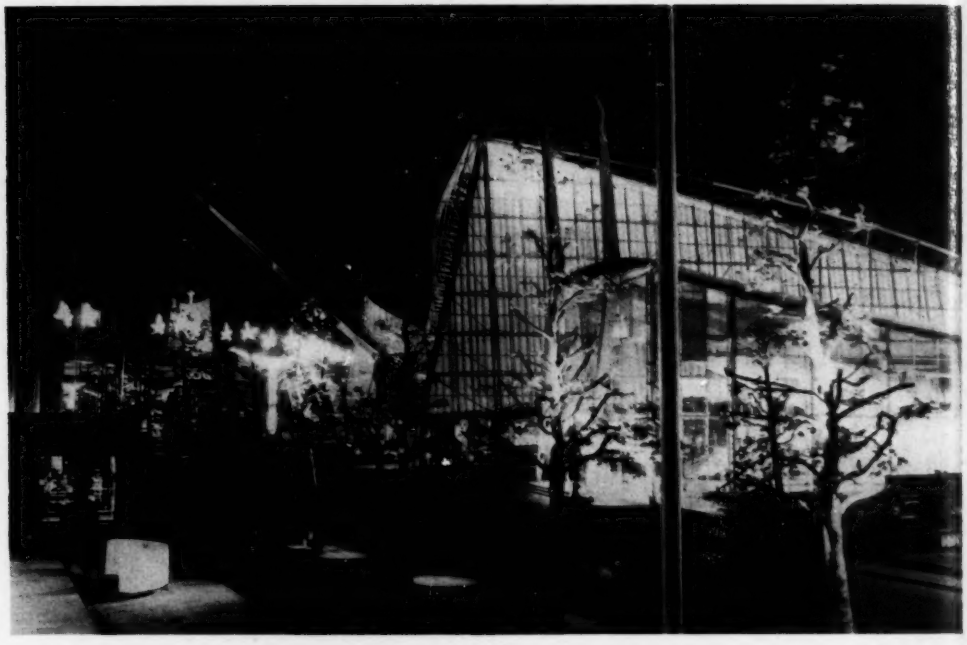


Fig. 13. The French pavilion in front of which is the Paris pavilion.

Fig. 14. The U.S.S.R. pavilion.

Table 1

Position	Type	Output of motors h.p.	Lighting power in kW	Total power kW
Rond point de la Passerelle	Single jet on glass block	3	2	5
Latin America	Cascades	10	5	15
Petite Suisse	Variable jet	7.5	17.5	25
Avenue Centenaire	Water ladder	780	160	940
Porte Benelux	Variable jets	58	85	143
Entrance Grands Palais	Straight jets and cascades	30	16.5	46
Flemish Garden	Sundry	10	5.5	15.5
Water buffet	Moving jets Vertical jets Rocking jets Candles Gargoyles Cascades	662	212	874
Belvedere	Variable jets	20.5	5.5	26
Osseghem Park	On rafts—various types	75	40	115
Congo garden	Fixed jets in spirals Rotating jets	11	16	27

(4.2) Water ladder

A water ladder embellishes the central part of the avenue leading from the Place de Belgique to the Porte Benelux. This stairway is divided into three flights, with 22, 17 and 12 steps respectively. The width of the stairway is 11 metres. Every step is 8 m. long and has a calm basin of 6 m. and a falling basin of 2 m. The average slope of the ground is 1 : 25 ; the levels between two steps in succession therefore differ by 0.32 m.

By an ingenious device the waterfall between two steps—a drop which should be 0.32 m.—is doubled. Each fall basin is connected by a pipe, not to the following calm basin, but to a second calm basin that follows it. In this way the height of fall between a calm basin and a fall basin is 0.64 m. To strengthen the impression of a movement of water in the fall basins each of these is supplied by the two adjoining calm basins. The water thus seems to come from all parts and creates a real water stairway or ladder.

The lighting of the basins comprises two rows of cold cathode tubes for each basin, accommodated in a peripheral groove placed in each basin below the level of water. For calm basins there is a row of white and a row of blue tubes, whilst for the fall basins there is a row of white tubes and a row of yellow tubes. The device for controlling the basins permits of their illumination with white or coloured light, and allows a play of light consisting of varying the colour of the basins in descending or ascending order.

(4.3) Water buffet

The existing water buffet, a relic of the 1935 exhibition, has been completely altered. It comprises a series of oscillating vertical jets and lateral rocking jets. In the centre, four fixed vertical jets have been retained. The whole of the water of the fountains then flows away by five overflows into a lower basin.

A flame 6 m. high, supplied with town gas, is installed in the middle of the jet of water. This flame is coloured by means of chemicals (sodium chloride, strontium nitrate, copper chloride). The lighting of the various jets of water is obtained by means of 212 immersed 1,000-watt projectors fitted with a moving 5-colour disc driven by a 1/3 h.p. motor. The total output used for the water buffet (lighting and pumps) is 874 kW.

(4.4) Fountains in Osseghem Park

Osseghem Park is traversed by a long and winding pond, where provision is made for seven sets of light fountains. Each set of fountains has a different sequence of water images regulated by a programme that is automatically controlled. The jets of water vary in height and intensity from fountain to fountain ; the largest attain a height of 15 m., others, in the form of geysers, are quite low. The lamps used vary from 200 to 500-watt according to the nature of the fountains.

(4.5) Congo fountain

The Congo garden has some characteristic ountains. One of these consists of a series of

13 fine jets starting from different points arranged in a spiral on a circular stair and ending in a central basin. The jets start each time from a flower bed and a series of projectors placed in the middle illuminates the fountain in the evening.

Other special fountains are installed in the garden. Mention may be made of a series of rotating fountains placed in the pergola and a large canal fitted with a set of fine jets falling into the middle thereof.

(5) Conclusions

The written part of this paper is of necessity incomplete as it has been necessary to condense a great deal of information into a limited number of words.

With the exception of the lighting of the national pavilions all the lighting which has been described in this paper was the responsibility of a Commission presided over by Mr. Van Goethem, chief architect of the exhibition, with the assistance of Mr. Baltus, the assistant architect. I have pleasure in stressing here the perfect collaboration which has never ceased to exist on the Commission amongst all its members.

I would also thank my assistant, Mr. K. Verbelen, for his help in preparing this paper, and Mr. J. Blower, architect delegate of the British section, who supplied me with all the data and photographs concerning the British section.

And this paper could not have been achieved without the help of Mr. G. F. Cole who kindly undertook the translation of the paper.

Discussion

Mr. A. H. YOUNG: I think words are really unnecessary after the magnificent display of slides. Firstly, I must stress that it is impossible in two or three days to get any idea of all the wonderful material there. After seeing Mr. Boereboom's slides I reckon I saw practically nothing at the exhibition! There is so much to see that it is impossible, even with the slides, to give you any idea of the vastness of the exhibition.

Mr. Boereboom, perhaps, did omit one or two things which I thought were excellent, although he did mention briefly the Belgian Civil Engineering exhibit—that pre-stressed concrete wing is wonderful. If you do get to Brussels, do go and see the Belgian pavilions. They have put on a marvellous show and their section of the exhibition is well worth a long visit.

As far as the exterior lighting goes, it must be remembered that it was a decision of the exhibition authorities not to put in a great deal of exterior lighting and it has been left to the pavilions themselves to throw light on the pathways and roads. This is particularly noticeable in the international section. There is very little applied lighting to the roads and gardens. Most of the lighting you have seen in the slides is in the Belgian section, but in the international section the British effort does stand out well. The exterior lighting of the British Government Pavilion is really good and I think the British effort as a whole is very fine. I was glad to hear Mr. Boereboom praise it. The fine effect of the indirect lighting on to the ceiling of the British Industries Pavilion has been lost because of the many high stands which have been installed.

The only time I wished we had had the film Mr. Boereboom mentioned earlier, was to show the Atomium at night. From the slides you are not able to appreciate the scintillating pattern of the lamps playing over the surface all the time. It is quite outstanding. I am told that this structure is to remain for the next ten years, so we shall have a chance of seeing it again.

I hope the world-wide interest being shown in the Brussels Exhibition will result in greater interest being taken in this country in external lighting. We have so many places which can be illuminated, and we have so many visitors, that a great deal more could be done.

Mr. J. M. WALDRAM: I had the privilege of seeing the exhibition twice—last October when it was being erected, and again quite recently. I also have tried to take colour photographs, but the colours in the lighting and the range defy the photographic process. Fine as the pictures are that we have seen they cannot capture the delicacy and give no real impression of size. Mr. Boereboom said that there were 17 miles of roadway in the exhibition: it seemed far, far more.

Vast as the exhibition is when finished, it gives no conception of the work which went into it. It was only when one saw the construction of some of those extraordinary buildings that one could appreciate the effort involved and I think the whole world will congratulate Belgium. They have also performed some feats in Brussels itself in a very great construction of roads, tunnels and buildings. One thing is their amazing attention to detail in such matters as accommodation and access. There is parking space for 30,000 cars and a helicopter service.

I agree with the previous speaker who praised the British Government exhibit, which I thought was outstanding. Its organisers deserve praise for having designed it for the man who goes to

look at it, not to give pleasure to the man who designed it. I left it with a quite unusual feeling of pride in British achievement.

Of the lighting exhibits I saw, two I would mention particularly : one is the lighting of the parabolic arch of the Reception Hall, and the other is the water ladder, which goes the full length (1,500 feet) of the avenue starting at the Place de Belgique, where Mr. Boereboom has been responsible for a water cascade which gives the impression of going up as well as down.

Dr. H. H. BALLIN : I have had two days at Brussels and I would like to raise only two technical points. I was intrigued by the cloverleaf street lighting fitting the author showed but I was surprised that there was a need for the 1,000-watt tungsten lamps in addition to the mercury fluorescent lamp. Has the author experimented without the tungsten lamps ?

The second point is, I suppose, a criticism. I thought the lighting of the trees was a little archaic. Some of the results of the lighting of trees at the Festival of Britain in 1951 were ahead of those at Brussels and a good deal of progress has been made since then. The use of tungsten lamps with colour filters was ordinary and could have been avoided. Why has fluorescent lighting been excluded from the solution there ?

The lighting of the fountains was excellent and many visitors enjoyed the play of colour.

Mr. F. L. CATOR : I too have seen the exhibition. I agree with Mr. Waldram that good as these slides were they certainly don't give you the real impression. That was particularly true of the British pavilion. Another feature of the exhibition which stood out was the façade of the main entrance hall which is best seen from the top of the Atomium. But good as it was, the façade was only second on my list.

The exhibition emblem, lighted by cold cathode tubing, was another outstanding feature as were the flashing lights on the outside of the Atomium. But to me, and here, perhaps, I cross swords with Dr. Ballin, the outstanding feature of all was the lighting of the trees in the park, lighted by numerous small lamps. I would like to have more details of the lights used.

I mentioned the flashing lights on the Atomium. How are those lamps replaced on the outside of those tremendous spheres—the top one is 365 feet above the ground. It must be quite a job.

At night time the American pavilion is outstanding. It is beautifully done, giving an impression of tracery. I thought that the Russian pavilion was garish. The Austrian pavilion appeared to be designed mainly for its night-time appearance.

As far as I could see the Philips pavilion doesn't appear to have an entrance. I should be interested to know if there is one.

Mr. S. ANDERSON: Could Mr. Boereboom give any estimate of the proportion of the total electrical load of the exhibition which is serving discharge lamps ; I imagine the proportion is probably larger than will have occurred in any concentrated area anywhere else in the world. Has this concentrated reactive load given rise to any particular problems ? Has he found a power factor rather lower than he would have liked in the distribution network ? Has he encountered any trouble in regard to harmonic currents in the supply system ?

Mr. R. BOISSEVAIN : One serious omission I felt was that the lecture makes no mention of the lighting of the roads leading to Brussels. Brussels has probably now got roads for the next fifty years and if we could have had some slides of the carriageways leading to the exhibition I think they would have been helpful.

I personally didn't think the British effort was so impressive. I thought the German pavilion was one of the most remarkable there. It was architecturally superb with tremendous detail.

Mr. A. J. DALTON : It is a great pity that it was impossible in these slides to give an idea of scale. Each pavilion has been condensed to the size of the slide although one structure may be four times the size of another.

From the photographic side I agree, as a photographer, that a lot of the subtleties of the lighting were missed in the colour slides. This exhibition is so wonderful that one ought to take every opportunity of getting the very best records that can be obtained. I would suggest that one proceeds in two different ways. First of all one has to be sure that one uses the right kind of film, an artificial light film. I should determine what was an optimum exposure to cover, so far as possible, the whole range of lighting, so that the photographs would have relative values, showing as well as colour differences, the respective intensities of light between one pavilion and another. Then I would take another set of photographs to produce the optimum effect of the lighting of each individual pavilion. The two sets would be quite different.

THE AUTHOR (in reply): First of all I must thank Mr. Young for his kind words and for opening the discussion in such excellent terms. I agree with him when he says that it is impossible in two or three days to take in the whole of the exhibition, for which at least a week is necessary.

I also appreciated very much his remarks regarding the Belgian exhibits and pavilions. It is true that the slides cannot give a true impression of the lighting of the Atomium, and that a film is necessary to show the effect of the apparently moving lights. Those who will not be able to come over this year to see the exhibition will perhaps be attending the meeting of the CIE in Brussels next year when they will have the opportunity of seeing the Atomium which will still be there. It is also true that the slides as a whole give an inadequate impression of size and colour.

I must thank Mr. Waldram for mentioning the work which has been done in Belgium on constructing new roads, tunnels and buildings. In fact all these public works may be considered as a part of the exhibition which gave us the opportunity to carry them out much more quickly than would otherwise have been the case.

I must thank Mr. Cator for his appreciation of the lighting of the trees in the park, and especially in the Avenue des Halliers. This lighting was achieved by the use of small 10-watt 24 V tungsten lamps housed in a metal fitting to protect them against rain. Each transformer feeds 30 of those lamps, that is, the number placed in one tree. The replacement of the lamps on the Atomium is done from the inside and causes no trouble. And I can assure Mr. Cator that the Philips Pavilion has an entrance—it even has an exit.

In reply to Dr. Ballin, the 1,000-watt tungsten lamps placed in the big columns of the Belgian section are necessary for emergency lighting. When there is a current failure in the main system the diesel unit is automatically switched on, but in the meantime the mercury lamps have been switched off and as you know they take some time to regain their full lumen output; that is why the tungsten lamps are included in these fittings.

A lot of work has still to be done on the lighting of trees as we are waiting for the trees to come into full leaf to complete the installation.

I can tell Mr. Anderson that so far we have had no trouble at all with the reactive load of the lighting installation. I may say, however, that all the discharge lamps are compensated so that the general load factor is near to 0.8. There has been no trouble in regard to harmonic currents in the exhibition. (We have had such trouble in the lighting of the tunnels of Brussels, probably due to the number of mercury rectifiers necessary for the electrical supply of the tramways in Brussels.)

In reply to Mr. Boissevain I would mention that there has been a great deal of effort put into the lighting of the roads leading to the exhibition, chiefly on the Petite Ceinture, but I have no slides of these installations.

Finally, I agree with Mr. Dalton that the slides are far from perfect, but that was due to the very short time I have had since the opening of the exhibition to take photographs and prepare them for presentation.

I sincerely thank all those who have made contributions to this discussion and I hope I have given adequate replies.

UDC 628.93

Lighting in Finland

By E. PÄIVÄRINNE *(Member)*

Summary

The first part of this paper reviews the general course of lighting development in Finland during the last few years and the influence thereon of local conditions. More detailed information is given on the principles which have led to practical solutions in particular fields such as the lighting of schools, offices, streets, hospitals, etc. Details of installations and lighting fittings are given and special reference is made to decorative fittings and to those which have been designed to give a controlled light distribution.

(1) Introduction

As a background to the presentation of some up-to-date features of lighting in Finland it may be useful to make a general survey of the course of development in lighting during the last few years in our country.

Some 10 years ago lighting practice for indoor working areas was mainly based on the use of general diffusing incandescent fittings—the opal glass globe in its various forms and sizes. The general illumination levels varied from 20 to 40 lux and local lighting was arranged where the more difficult visual tasks were carried out. At that time lighting engineers were naturally anxious to raise the general illumination levels by various means, e.g., very often—perhaps too often—by making most of the room surfaces almost white. An increase in the use of electricity was not easily accepted at that time.

The general illumination levels began their more marked rise with the foundation of the Lighting Society and the introduction of fluorescent lamps; both these events occurred just about 11 years ago. At the present time, when fluorescent lighting has, we hope, got over most of its teething troubles, general illumination levels of 150 to 300 lux are not uncommon in new and reorganised working areas.

Changes in outdoor lighting practice, especially in street and road lighting, have not been so great or so general as in indoor lighting. Discharge lamps, which have made it possible to increase the illumination economically and without a marked rise in power consumption, are used only in the largest towns; and even there chiefly for ma streets. Fittings with a more controlled lig.. distribution have come into use with discharge lamps. However, we now expect quicker development in outdoor lighting because of the influence of the new exemplary installations and because of great increases in motor traffic.

When considering the lighting practice of tomorrow, we have little guidance from our own laboratory investigations about fundamentals in seeing, because of the limited possibilities for research work in our country. We have, however, tried to find answers to lighting problems by making experiments and observations in the practice itself. As building activity has been relatively lively since the war there have been new opportunities for development in lighting; the new building has also raised a demand for better lighting in surroundings where our modern architecture has left its own strong mark.

(2) Lamps

The electric lamp industry in Finland is relatively young. It was not until the middle of the 1920s that the first incandescent lamps were manufactured. Since that time development has gone rapidly forward and at present about 900 types and sizes of incandescent lamps are made. Compared with 1939, lamp production has been trebled. The calculated average rating of manufactured incandescent lamps is at present 49 watts, which means an increase of 10 per cent. compared with the figure for the year 1953.

The manufacture of incandescent reflector lamps started some years ago and these lamps have been very popular. The wattage range varies from 40-watts to 150-watts. Of these the 40-watt reflector flood lamp has been much used, for example, in small local lighting fittings in homes.

The first Finnish hot cathode fluorescent lamps were introduced in 1947. The range of lamps manufactured at present includes the 15-watt, 20-watt, 30-watt, 40-watt and 80-watt ratings in conformity with standardised dimensions. Lamps are available in seven different colours of " white " and coloured lamps are also made. About one

The author is with the Finnish Lighting Society (Valosto). The manuscript of this paper was first received on January 27, 1958. The paper was presented at a meeting of the Society at Eastbourne on May 1, 1958.

Fig. 1. A classroom in Tapiola School. Illumination level 300 lux. The reflectors are made of anodized aluminium.

Fig. 2. The dining hall of Tapiola School. This can be divided into smaller spaces which serve as sewing class, library, etc. Lighting is by recessed louvred 2×40-watt fluorescent fittings and by indirectly illuminated embrasure in the ceiling. Illumination level 300 lux.

half of all fluorescent lamps are of the " Standard white " type, but the popularity of De Luxe lamps —especially of " Warm White De Luxe "—is increasing.

The production of colour-corrected mercury lamps has started quite recently, mainly due to street lighting needs.

There is only one lamp factory in Finland ; but it can be said that the range of lamps made there has sensitively followed the continuously growing needs of lighting practice in our country.

(3) Lighting Practice

(3.1) Schools

Lighting in school classrooms has been a subject of continual interest in our Lighting Society, as it is not of the same nature as, for example, shop lighting, which is inclined to develop by itself as a result of commercial competition. Apart from recommendations for minimum illumination values, we do not at present have any published standard practice for lighting in schools. However, such

Fig. 3. An office illuminated by 2 × 40-watt fittings with specular aluminium side reflectors. Illumination level 300 lux.

Fig. 4. Industrial interiors with low ceilings are usually lit by 2 × 40-watt fluorescent fittings to a level of 250 lux.

lighting matters are often dealt with by articles in various magazines.

The first fluorescent fittings in classrooms were, like the opal globe incandescent fitting, of the general diffusing type with a glass shield round the lamp. As illumination values increased glare problems arose and about five years ago the direct-indirect, louvred pendant fitting came into common use. In a classroom of normal size it was usual to install six fittings each provided with two 40-watt fluorescent lamps. The fittings were placed in two longitudinal rows. This solution is very often used even today, especially in the relighting of old schools.

On the other hand, direct lighting has become common, the fittings being either recessed into the ceiling or mounted direct on it. This is due to the popularity of acoustic panel ceilings of restricted height. Recessed fittings with light diffusing shields or white louvres at the ceiling opening are not considered to give adequate seeing comfort at high illumination levels (see section 3.5) and as an

alternative we therefore have such installations as those in the Tapiola School. (See Figs 1 and 2.) The 40-watt single lamp recessed fitting in the classroom has been constructed so that no light comes from the fittings to the desks from directions which would produce indirect glare. This is achieved by an asymmetrical specular aluminium reflector which distributes the light 10 deg. backwards and 60 deg. forward from the vertical plane. This light distribution eliminates also the direct discomfort glare in principal directions without the use of louvres or other devices which decrease the efficiency and make maintenance very difficult for the normal school staff. Shadows produced by this lighting, as is usual in directional fluorescent lighting, are strong enough for good modelling but are not disturbing.

Our experiments have not helped us to find direct incandescent lighting solutions which satisfy the various demands sufficiently well. This may be due to the " point source " character of the incandescent lamp, which requires a more indirect fitting. Taking into account our relatively long annual burning time, indirect or semi-indirect lighting installations with incandescent lamps have proved to be very expensive and they are not used even in rooms where a greater ceiling height would make it possible.

(3.2) Offices

The general development of office lighting is much the same as that of school lighting. Most offices are now provided with direct-indirect 2 x 40-watt louvred fluorescent fittings: the fitting with specular aluminium side reflectors (Fig. 3) has gained most popularity. This fitting has a very low luminance in the direct glare zone. Each row of desks is illuminated generally by its own row of fittings.

An installation very similar to that shown in Fig. 1 has given good results also in an office where many people are facing in the same direction. This solution eliminates indirect glare—and dilution of the actual physical contrasts in the visual task on the table.

Indirect lighting or luminous ceilings are seldom used as a means of diminishing the disturbing effect of indirect glare or shadows. Both are expensive, and the luminous ceiling is difficult to maintain.

(3.3) Factories

For the general lighting of factories with low ceiling heights ordinary 2 x 40-watt louvred fluorescent fittings of white steel or aluminium are mainly used. (Fig. 4.)

The lighting of high and large area industrial spaces is sometimes achieved by means of 80-watt fluorescent lamps in order to soften shadows. To make maintenance easier the lamps are often concentrated in multi-lamp fittings, where each lamp has its own reflector of anodised aluminium.

When maintenance is difficult or the area is very narrow, the colour-corrected mercury lamp in a deep reflector is gaining favour for the lighting of factories with high ceilings.

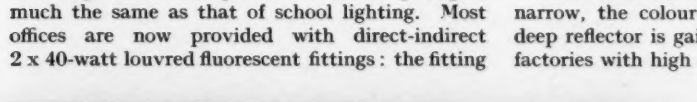


Fig. 5. A restaurant illuminated by recessed dark louvred incandescent fittings and low hanging diffusing fittings as attraction centres. Walls are dark painted and the dark ceiling is covered by unpainted wood construction.

(3.4) Problems with recessed fittings

Indoor lighting installations using recessed or ceiling-mounted incandescent and fluorescent fittings have greatly increased during the last few years. We have found that some rather important problems are involved and these problems are briefly discussed in the following.

In order to make it possible to prepare ceiling openings before the supplier of lighting fittings is known, and also to make it possible to manufacture recessed fittings as stock goods, it was felt necessary to standardise some ceiling opening dimensions for the commonly used types of incandescent and fluorescent fittings. The standardisation was carried out by the Lighting Society in collaboration with the associations of architects and fittings manufacturers.

Heat production inside a recessed incandescent fitting with a high wattage lamp presents a considerably bigger risk of fire than in the case of other types of fittings. In order to reduce this risk to a minimum the Electrical Inspectorate (the Finnish electrical safety authority) issued rather strict constructional requirements, including minimum dimensions for recessed incandescent fittings.

Recessed and ceiling-mounted fittings have a tendency to produce so high a brightness contrast against the ceiling that they are glaring or at least disturbing. This is the case especially when there is an ordinary light diffusing screen or even a white louvre under the lamps. Decreasing this contrast by, for example, enlarging the diffusing area and thus decreasing its luminance still leaves the ceiling very "active." This is so even with the totally luminous ceiling; it has the greatest apparent brightness in a room and is, therefore, considered to be suitable only in some special cases. Contrasts are needed to make a room alive, but it has been felt that the contrast between ceiling fittings or between a completely luminous ceiling and the rest of the interior is not so desirable as contrasts between certain other parts of the interior. If bright luminaires are essential in the contrast pattern of an interior they are often placed much lower in the room (Fig. 5) and the luminance of separate ceiling fittings is kept small, at least from the normal directions of view.

As a result of these observations the use of ceiling fittings with carefully shaped specular reflectors of anodised aluminium has greatly increased. These reflectors keep the apparent brightness of the fitting low in directions from which they normally are seen and distribute the light in other directions, either concentrating it or spreading it, depending upon the general purpose of the lighting. In addition to the advantages in brightness control it has been possible in many cases to avoid the use of louvres, which reduce efficiency, make maintenance more difficult and also prevent a wider distribution of light when this is needed.

(3.5) Streets and roads

The 125-watt and 250-watt colour-corrected mercury lamps are now coming into use for lighting main streets in the larger towns. When improving the illumination of old streets the previous diffusing incandescent fittings are still used but

Fig. 6. A lighting installation of a suburban main street by 125-watt colour-corrected mercury lamps.

Fig. 7. Street lighting lantern for 140-watt sodium lamp with clear plastic bowl and anodized aluminium reflectors.

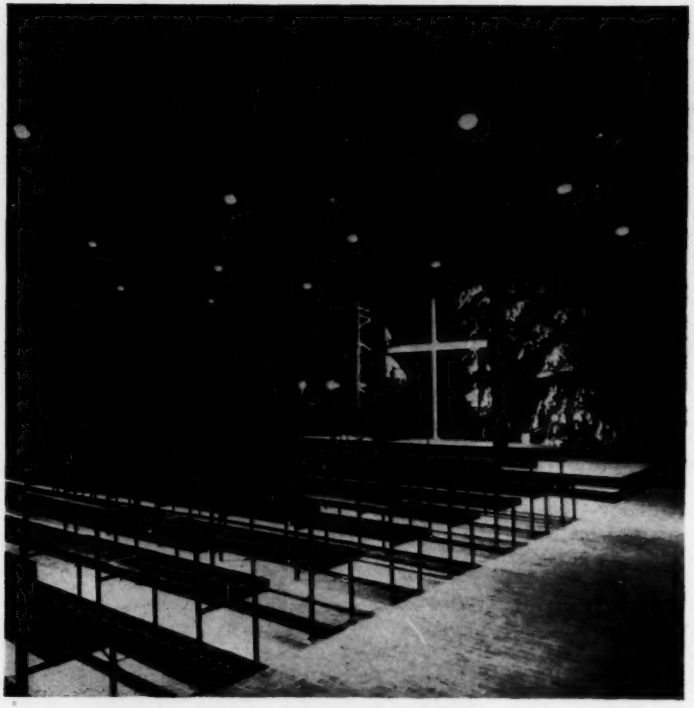


Fig. 8. The whole front wall in the Chapel of Otaniemi is of glass.

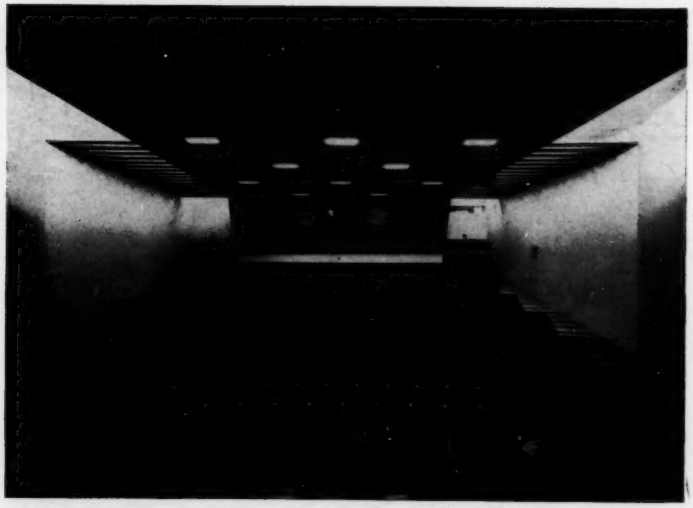


Fig. 9. The auditorium of the Minor Stage of the National Theatre of Finland.

Fig. 10. The Central Hospital of Middle Finland in Jyväskylä.

Fig. 11. A ward in the Central Hospital of Middle Finland.

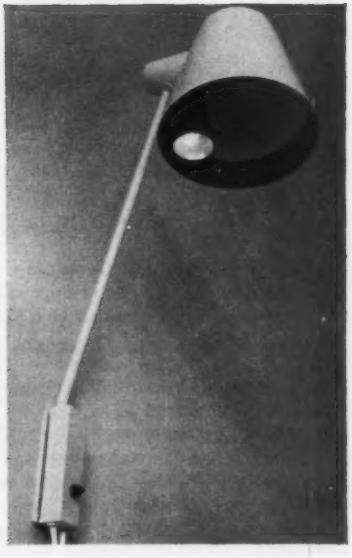


Fig. 12. (Right) Bed lighting fitting.

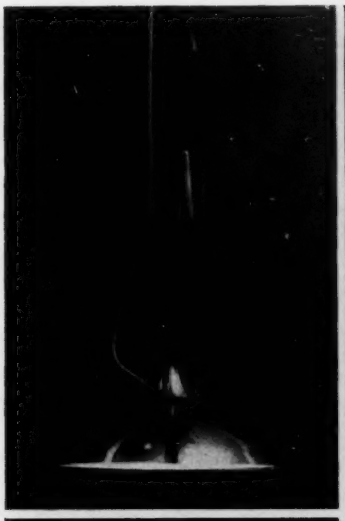


Fig. 13. (Top left). An adjustable pendant fitting of polished brass.

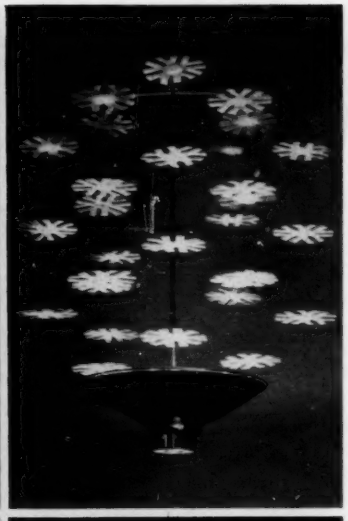


Fig. 14 (Top right). Mobile of 30 "snowflakes" above the direct-indirect reflector of polished brass.

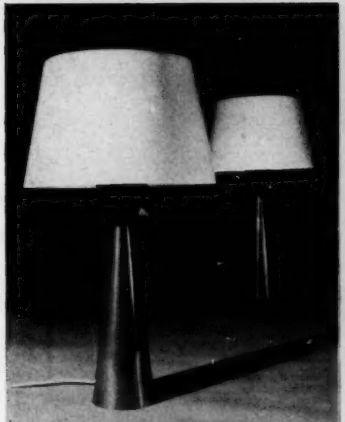


Fig. 15. (Bottom left). Table fitting with dense opal plastic reflector.

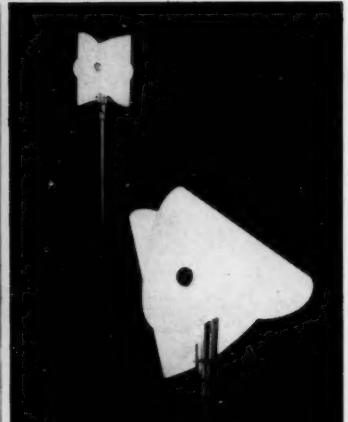


Fig. 16. (Bottom right) Floor fitting with adjustable reflector of dense opal plastic

incandescent lamps are being replaced by the mercury lamp, sometimes even by the mercury reflector lamp.

In new suburban streets normal colour-corrected mercury lamps are used in cut-off reflectors of anodised aluminium (Fig. 6). The lamp is in a horizontal position in the reflector in order to achieve not only a relatively broad light distribution, but also an effective cut-off, which is appreciated by people living in low houses nearby. The previous oval reflector fittings which were imported into Finland had the lamp in the vertical position and they were not suitable for long light sources.

The spacing of poles is intended to be kept between 30 and 35 metres. Fluorescent lamps are little used in outdoor installations because of temperature difficulties during the winter.

On main roads leading into towns, 140-watt sodium lamps have also been used. The fitting (Fig. 7) has a light distribution which is broader than that of the above-mentioned mercury fitting, and is thus more effective in producing the desired luminance on the road surface. The introduction of sodium lamps in large-scale installations has diminished the prejudiced attitude against them arising from the saturated yellow

colour of sodium light, strongly emphasised earlier when sodium lamps were used locally at crossings, etc., thus contrasting with the white lights nearby. The effect of colour adaptation is perhaps still greater in large-scale installations where the surrounding is covered with snow. In spite of the broad light distribution complaints of discomfort glare have not been made, and sodium lighting is much appreciated by drivers.

(3.6) Miscellaneous installations

The Chapel of the Students Village at the Technical University in Helsinki (Fig. 8) has aroused attention. There is a "living" altar-piece—Nature herself—and a cross illuminated at night is placed outside in front of trees. Interior lighting is entirely direct, leaving the walls dark, and the illumination level is relatively low (some 25 lux) in order to prevent disturbing reflections from the window wall. The lighting fittings are also asymmetrical so that the opening of the reflector cannot be seen at the window.

The so-called "Minor Stage" of the National Theatre (Fig. 9) represents the latest theatre technique in Finland and has the first large installation of electronic dimmers in our country.

In the ward lighting of the Central Hospital of Middle Finland (Figs. 10, 11, 12) an attempt has been made to avoid discomfort to patients from ordinary diffusing opal fittings in the middle of the ceiling. The illumination at bed level comes partially from recessed ceiling fittings in which a cut-off in the distribution prevents light from reaching the eyes of a patient. This is achieved by the use of a specular reflector in the fitting. The light to the bed comes partially also from the local bed fitting and this light is under the control of the patient. Indirect light from the bed fittings and wall fittings gives a moderate but not too high luminance to the ceiling and walls. In the bed lighting fitting there is a small separately controlled lamp in a direct reflector for night use.

(4) Decorative incandescent lighting fittings

Figs. 13, 14, 15 and 16 illustrate some modern incandescent decorative lighting fittings.

The fitting in Fig. 13 is an example of a series of fittings employing polished brass. They have been popular in Finland for some years and they have been exported to other countries, including the U.S.A.

Figs. 15 and 16 illustrate more recent fittings, mainly made of plastic, colour sprayed aluminium and satin finished opal glass. Some of these have received international awards.

Discussion

Mr. J. G. CHRISTOPHER: It is always a great pleasure to us when one of our overseas visitors comes here to give some indication of lighting practice in his own country. It is of great value for illiminating engineers to be constantly refreshed by taking note of the practice in other countries, particularly countries such as Finland where such a lead has been given in design.

When reading Mr. Paivarinne's paper I was struck by the fact that in Finland there are several factors which affect lighting technique, with which we do not have to contend over here. First of all, there are the long hours of darkness; secondly, in relation to street lighting, they have snow on the ground in some parts of Finland for up to five months of the year.

The average lamp wattage of 49 watts which they use in Finland is probably a good deal lower than over here and no doubt in view of the progress they have made since 1953 this will continue to rise.

I was interested to hear of the use of mercury reflector lamps and I was very intrigued by the living altar-piece at the Chapel of the Students' Village at the Technical University in Helsinki, which looked very beautiful. I was also interested in the installation of electronic dimming in the National Theatre of Finland.

The problem of avoiding discomfort to patients in hospital wards has been with us now for many years, and the solution put forward by Mr. Paivarinne is a very interesting one.

There are two points on which I should like to comment. First of all, in a country where 40-watt and 80-watt fluorescent tubes are available it is interesting to note that most of the fittings to which the author refers are single or twin 40-watt. In this country we feel that the 80-watt tube is a better economic proposition and therefore most of the tubes we use are 80-watt. It would be interesting to know the reason for the concentration on 40-watt tubes in Finland.

Another point I noticed was the extensive use of specular reflectors. In this country we rarely use specular reflectors except in very specialised cases, whereas in most of the slides shown use is made of fittings incorporating this type of reflector. I was interested to compare the school classroom lighting using specular reflectors with the installations of asymmetrical lighting for drawing offices, referred to by Dr. Ballin. Both have a similar approach. In school classrooms this is probably practicable because seldom would the layout of desks be changed. In offices, however, difficulties

might arise because of the desire to change the desks around, in which case the lighting might become unsuitable.

One other thing, probably linked with the use of specular reflectors, is the relatively small use of acrylic enclosures which are used extensively for commercial lighting over here.

Mr. E. HARRISON-JONES : I was rather intrigued by the use of anodised aluminium, more on the grounds of cost than anything else, and particularly as used in the Tapiola school. We all know what sort of money we have to spend on school lighting in this country—we are lucky if we get an allocation to do a reasonable job—but one appreciates that the situation is somewhat different in Finland because of their longer hours of darkness. An installation of the type shown, with aluminium as the metal and with an anodised finish, must be expensive. Perhaps Mr. Paivarinne has a rather more generous budget for school lighting than we have. Is this typical of the sort of lighting installation that goes into the schools of Finland today, or is this a special school ?

My remarks apply similarly to office lighting. The use of anodised aluminium in office lighting in this country would produce economic difficulties because it would be very difficult to sell a fitting of this type, although no doubt it would have very good brightness control. Again the use of the 4-ft. 40-watt lamp and the rather expensive finishing process puts up the cost. It is interesting to note that you can apparently do that in Finland but I don't think we could get away with it here.

The only other point in the written paper, which I think was partly answered in the presented version, is the use of 80-watt tubes in order to soften shadows. I believe Mr. Paivarinne said that that was in relation to point sources, but the written paper does not state this. I see that the 80-watt tube has been used to some extent in industrial lighting—in this country we use the 80-watt tube automatically but the 125-watt tube is even better. But whereas in Finland they appear to have the 80-watt tube and all the things that go with it, the use of the 40-watt tube predominates. Is there a production or commercial reason for this ?

Mr. A. G. PENNY : One of the things that had always intrigued me about Finland is the reputation that the architecture and the arts have in that country for what I would call a disciplined art ; they seemed to be so effectively careful in avoiding the flamboyancies of the more Latin countries. Consequently it came as a shock to me when I was told that the Finns are not Nordic people at all—they come from the East. I sometimes wonder now, why, in their architecture and their approach to artistic problems, one rarely sees any exotic touch.

Whilst they have given a lead to the rest of the world in the direction of controlled artistry, I hope that it will not be too long before the lighting engineers in Finland can have all the tools that engineers in other countries now have, even if it does result in some loss of control.

There is a trend emphasised in Mr. Paivarinne's paper that Dr. Ballin may have missed. It is that the practical lighting engineer is now dominating the proceedings in place of the research scientist with his " lumens per watt " ; a trend which is perhaps best illustrated by the growing use of highly loaded fluorescent tubes like the 5-ft. 80-watt type.

There is a reference in the paper to the increased use of the de-luxe warm white colour. Is there a psychological reason for this desire of the Finns to have a warm colour ? In the tropics cold colours are used to give a feeling of coolness which I can understand, as in the tropics they have difficulty in keeping the houses cool, but in the Northern countries where house heating is so effective I do not quite see why a warm colour should be chosen for psychological reasons. I would like to know what influences their choice in the matter of colour.

On the question of street lighting one thing interests me and that is the use of reflectors. I have great difficulty in finding out why other countries still use reflectors as part of the light control mechanism. Refractor fittings are used here to a great extent, and as in this country we have some of the best street lighting in the world I would have expected other countries to profit by our experience and use refractors more frequently.

Mr. D. W. DURRANT : I would like to ask a few questions regarding aluminium reflectors :—are they made from super-purity or commercial grade aluminium ; are they polished before anodising ; is the surface highly specular or slightly diffuse ?

THE AUTHOR (in reply) : In reply to Mr. Christopher and Mr. Harrison-Jones, I think the reason why 40-watt fluorescent lamps are more used than others may be that they were the first type which came into use. (As far as I know the 80-watt lamp was the corresponding type in England.) There may be other reasons too, e.g. in spaces with a low ceiling height the 40-watt

lamp is well suited for producing good quality lighting of the order of 15 to 30 lm/ft². The 80-watt lamp will perhaps be more used with increasing general illumination levels.

It is important to remember that the relatively high cost of electricity and the relatively long annual burning time of artificial lighting demands a more effective and careful control of light in our country than in many other countries and these factors, together with advantages in brightness control and in maintenance, will perhaps cause a still increasing use for specular reflectors in many kinds of fittings. In spite of the higher initial costs of the open specular reflectors, their lower annual running costs make them even more economical than the ordinary louvred diffusing reflectors. This is the case also with the single-lamp asymmetrical specular fittings used in Tapiola school. They have also been found more economical than the ordinary two-lamp fluorescent fittings either with a louvred bottom or with an opal acrylic enclosure. This classroom lighting solution is very young and though it has been adopted also for other schools, as yet it is to be considered as a special type of classroom lighting.

In reply to Mr. Durrant, I can say that most specular aluminium reflectors are made from super-purity aluminium. The material for the bent trough reflectors has generally only a thin layer of this, but the reflectors for incandescent and mercury fittings are made from homogeneous material. The reflectors are polished before anodising but not mechanically, except in the case of projector reflectors. Both highly specular and very slightly diffusing surfaces are used, the former finding more use in projectors and the latter in ordinary fittings.

Mr. Penny raised the question about refractors versus reflectors in street lighting fittings. The refractors are not used in our country mainly because our industry has not been able to offer them at competitive prices.

Regarding the colour choice of fluorescent lamps, the increasing popularity of the de-luxe lamps shows, for instance, that the people prefer to keep a healthy shade of red on their skin. That the most popular de-luxe lamp is the warm white type may be because our general illumination levels are not so high that cooler light colours would give a pleasant atmosphere and an impression of a cheerful sunny day.

Additions to the List of Members

The following applicants have been duly elected by the Council to membership of the Society :—

Sustaining Members

London Typographical Designers Ltd., 90 Ebury Street, London, S.W.1.
Representative: G. A. Thompson.

Lumenated Ceilings Ltd., Alliance House, Caxton Street, London, S.W.1.
Representative: W. J. Walpole.

Corporate Members

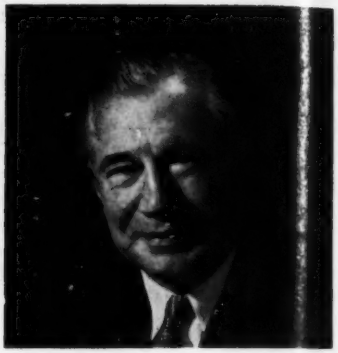
Ash, B. G.	Roadside Cottage, Kingshill, Nailsea, Somerset.
Bell, R. W.	Oakham House, Grimsby Road, Caistor, Lincs.
Berry, A. W.	116 Petersham Road, Richmond, Surrey.
Billings, R. H.	49 Croxteth Road, Liverpool, 8.
Boanas, E. S.	29 Ampleforth Grove, Willerby Road, Hull.
Burrell, C. H. G.	The Lodge, Clapham Road, Bedford.
Cahn, H. L.	3 Alkalai Street, Tel-Aviv, Israel.
Cole, G. J.	70 Armley Road, Anfield, Liverpool, 4.
Connell, R.	110 Rokeby Park, Hull.
Curtis, C. E.	"Ghyllfoot," Longhorsley, Northumberland.
Dobson, W. N.	62 Welbeck Road, West Harrow, Middlesex.
Fletcher, W.	41 York Road, Hull.
Gaynor, C. E.	P.O. Box 781, Johannesburg, South Africa.
Harvey, I. L.	"Craigmore," 53 Wymersley Road, Hull.
Healey, K. A.	4 Ormerod Crescent, Ormerod Road, Priory Road, Hull.
Hirst, J. L.	"Brantwood," 60 Station Road, Burley-in-Wharfdale.
Iddison, W. L.	189 Highgate, Heaton, Bradford, 9.
James, R. E.	62 Aintree Avenue, East Ham, London, E.6.
Newman, A.	37 Kingsway Avenue, Levenshulme, Manchester, 19.
Robinson, J. N. H.	23 Loncin Mead Avenue, New Haw, Weybridge, Surrey.
Smith, A. D.	The G.E.C. Ltd., Magnet House, Union Street, Plymouth, Devon.
Threlfall, A. J. C.	The British G.E.C. Ltd., Queens Buildings, Hong Kong. P.O. Box 15.
Tricker, C. S.	3 New Cottages, Woodham Mortimer, Maldon, Essex.

Transfer from Student to Corporate Membership

Baker, J. E.	Woking Golf Club, Hook Heath, Woking, Surrey.

Mr. Guy Campbell

(1887—1958)



No story of the development of electric lighting during the past fifty years would be complete without tribute to the great efforts made by the late Horatio Guy Campbell.

Mr. Campbell, who was Chairman and Joint Managing Director of The Benjamin Electric Ltd., died on August 4 in his seventy-second year. Until 1957 he was also Chairman and Joint Managing Director of Holophane Ltd. He was an original member of The Illuminating Engineering Society.

Mr. Campbell's introduction to scientific lighting was with the Holophane Company in New York, but it was not long before he returned to his native land where for a short time he was with Holophane Ltd., London, before joining The Benjamin Electric Ltd., then at Rosebery Avenue.

There are still some of us left who remember the dapper and energetic little gentleman who toured the electricity industry in Gt. Britain with his demonstration box and story of "Light on the object and not in the eye." How little informed then was the industrial world on the benefits of what has now become known as "suitable and sufficient lighting"! It was a hard fight indeed to make much headway in convincing users of the benefits of good lighting in the early 1900's when the tungsten lamp was in its infancy with a reputation of great fragility and high maintenance costs. The spark of recognition of the science behind lighting was fanned to greater sparkle by the formation of the Illuminating Engineering Society by such enthusiasts as Gaster and Dow.

Guy Campbell saw at once the great benefits such a Society would bestow upon the development of his pet subject, and from those early days and throughout his long career he was always a ready giver of his services, advice and support to assist in the development of the I.E.S.

It must be acknowledged that Guy Campbell's great ability was on the sales side. He recognised that a profitable industry needed vision, unbounded energy and a missionary mind, which together should promote a profitable business with money to spend on research and the wherewithal to promote the acceptance of good lighting.

Many may wonder what sort of man this was, especially if they never had an opportunity of meeting him. He was an outstanding mixture of both the serious and lighter sides of life. Many will remember the gay laughter, quick appreciation of jokes, and his gladness in being in the society of the electrical world; yet beneath this all was a very serious attitude not only towards the development of lighting and his Company, but towards life as a whole. For example, he had an amazing insight and appreciation of the political and economic conditions of the U.S.A., and to listen to him on this subject one might have thought one was listening to some outstanding political character expressing a view on the relationship desired by Gt. Britain with the U.S.A. His knowledge of the lighting industry throughout the world was complete, and he could, with great emphasis, explain why Gt. Britain, while not perhaps being quite so far advanced as the U.S.A., was nevertheless doing an excellent job in informing all of the benefits of good lighting.

Again, Guy Campbell was a great student of both national and international economics, and it was always a pleasure and an education to listen to him forecast the future, whether it would be for good or for bad. Underneath his forecasts was always a thought that the lighting industry need not run parallel with national or international depressions or success, and not only did this keep his own mind on the solid belief that the future of lighting should be growth upon growth, but it also led those who worked for him and with him and all he met, to the same belief.

He was a very good mixer and enjoyed the friendship of many amongst those in the lighting industry not only in the United Kingdom but throughout the world. He was also a Liveryman of the Worshipful Company of Clockmakers, and took more than average interest in horological problems.

Mr. Guy Campbell's passing has severed the connection with many famous engineers in the lighting industry. Perhaps one who should be

mentioned is Haydn Harrison, well known particularly in connection with street lighting.

It is perhaps a fair picture to give of Guy Campbell to say that he was a man with a great vision, a bold heart, and a great understanding that details of life and work must be considered together with the main plan. He will be missed by many, and it is perhaps unfortunate that his failing health prevented him from meeting more of the younger generation within the industry. He will always be remembered as a pioneer in the foundation and development of scientific lighting for the good of humanity in general and of the industrial world in particular. A.E.I.

Annual General Meeting

The annual general meeting of the Illuminating Engineering Society was held at the Winter Garden Pavilion, Eastbourne, at 4.30 p.m. on Monday, May 12, 1958. The President, Mr. E. B. Sawyer, was in the chair. The Secretary read the notice convening the meeting and the statement of the auditors for the year ending December 31, 1957.

In presenting the report of the Council the President referred to a number of specific points. An important development in 1957 had been the adoption of the new constitution which had corrected a number of anomalies which had crept into the constitution over a number of years and had also introduced the new class of Diploma Member which was regarded as an important step towards the recognition of the professional lighting engineer. The President expressed thanks to Dr. W. E. Harper for his chairmanship of the Extraordinary General Meeting at which the new constitution had been approved. He reported that the proposal to change the name of the Society which had been considered at the same meeting had been defeated.

The new rates of annual subscription had come into operation at the beginning of 1957. As had been anticipated there had been some loss in membership during the year but during the period January-April, 1958, which was not covered by the present report, a record number of elections had been approved by the Council.

An important step taken during the year was the re-formation of the Technical Committee. One of the objects of this committee is the presentation of information on lighting matters in a form which can readily be used by members, the industry and users of lighting. The committee was already engaged on a number of such matters.

Two outstanding Centre activities were the conference and exhibition on domestic lighting arranged by the Manchester Centre, and the second week-end meeting of the Edinburgh, Glasgow and Newcastle Centres at Peebles. The President expressed the thanks of the Council to the chairmen, honorary secretaries and committee members of all Centres and Groups for their work during the year under review.

The thanks of the Society were also expressed to Sustaining Members. The President said that the work of the Society had a considerable influence on the prosperity of the lighting industry. There are, however, many firms in the industry which do not support the Society as Sustaining Members and he hoped that renewed efforts would be made by members to secure their support. A number of large commercial concerns already recognise the value of the Society and support it as members; it was to be hoped that many more would follow this example.

During the year preparations had begun for celebrating the Society's Golden Jubilee in 1959. Committees had been set up within each Centre and in London and it was hoped that every member would collaborate to ensure the success of the Jubilee and to help bring the Society to the notice of as many people as possible. In conclusion the President referred to the announcement made in the last annual report to the effect that improvements were to be made in the style and appearance of the Society's Transactions. Though this change was not made in 1957, the first issue of the Transactions in its new form had been published and had been very well received by members.

There being no comments on the report or accounts from members, Mr. John Walsh then proposed their adoption and also a vote of thanks to the President, officers and members of Council for their management of the Society's affairs during 1957. This was seconded by Mr. P. Hartill. The motion was approved unanimously and the report and accounts were declared adopted.

The President then reported on the election of officers and members of Council for the 1958-59 session. Subsequent to the publication of the

eight Council nominees for ordinary members of Council two additional nominations had been received in respect of Mr. G. E. Kemp and Mr. R. A. Hounslow. A ballot had therefore been held and the report of the scrutineers was presented showing that the members whose names are given below were elected. The names of officers and new members of Council were reported as follows :—

President : Mr. C. C. Smith.

Vice-presidents : Mr. F. X. Algar, Mr. N. Boydell, Mr. H. G. Campbell, Mr. A. H. Olson, Mr. D. L. Tabraham.

Hon. Treasurer : Mr. A. W. Gostt.

Hon. Secretary : Dr. W. E. Harper.

Hon. Editor of the Transactions : Mr. H. Hewitt.

Members of Council : Mr. E. S. Evans, Mr. J. T. Grundy, Dr. C. A. Padgham, Mr. W. T. Souter, Mr. D. A. Strachan, Dr. J. W. Strange, Dr. A. Roberts, Mr. T. Roberts.

A vote of thanks to the scrutineers, Mr. D. Prince and Mr. L. W. Cole, was proposed by the President and carried.

The President expressed the thanks of the Society to those retiring from office and in particular thanked Mr. J. G. Holmes for his valuable contributions to the Society during the years in which he had been Honorary Secretary, and Mr. W. Robinson for taking responsibility for the Society's finances during the past three years. Appreciation was also expressed of the work of the Secretary and staff during the year.

The remuneration of the auditors for the current year was proposed by Mr. A. H. Willoughby and seconded by Mr. E. F. Edwards and carried unanimously.

There being no further business the meeting then terminated.

Additions to the Library

Books may be borrowed from the library by members on personal or postal application to the Secretary, The Illuminating Engineering Society, 32 Victoria Street, London, S.W.1. Certain books which are either irreplaceable or which can only be replaced with difficulty cannot be removed from the library but are available for inspection only. Books on loan must not be retained by members for more than two weeks.

The following additions have recently been made :—

Reference No.	*Title*	*Author*	*Date*
1/83	Planned Artificial Lighting	J. W. T. Walsh	1956
6/8	Lighting the Stage (2nd edition)	P. Corry	1958
6/9	The Technique of Stage Lighting	R. Gillespie Williams	1958
11/30	Electrical Discharges in Gases	E. M. Penning	1957
15/24	The Measurement of Colour (2nd edition)	W. D. Wright	1958
15/25	The Reproduction of Colour	R. W. G. Hunt	1957
23/44	We live by the Sun	J. G. Cook	1957
23/45	Generation, Transmission and Utilisation of Electrical Power	A. T. Starr	1957
23/46	Siemens Brothers 1858-1958	J. D. Scott	1958
23/47	The Social History of Lighting	W. T. O'Dea	1958
23/48	Electronics for Everyone	M. Upton	1956
23/49	Lighting Practice in Japan		1956
23/50	Lichtarchitektur	W. Kohler and W. Luckhardt	1956
2/13	Underground Lighting in Mines, Shafts and Tunnels	A. Roberts	1958

A complete list of books in the library may be obtained from the Secretary.

Design of the Visual Field as a Routine Method*

(Discussion)

Mr. RONALD CROFT: It is pleasing that Mr. Waldram has now given his excellent method in full in the Society's Transactions.

The work sheet is well devised and the use of average in service reflectances and light output ratios a sound pointer to the future.

The author's views on whether the adaptation value of the apparent brightness should be based on (*a*) a fixed line of vision, (b) a fixed plane of vision, or (c) random vision would be helpful. If this were decided it would be possible to evaluate it without the guesswork, which would be the total of the experience of most of us in this matter.

I think it should be made clear that the wall illumination factor relates to the illumination on the " w " wall (or have I got it wrong ?). In the example this is the shorter wall, and because the long wall is only half as long again the illumination factor for it is little different, 0.36 in this case. In other cases the error might be greater.

For the above reason and also because average values of flux are used to obtain the direct components of illumination, I prefer average values for the reflected component. [See R. O. Phillips. Transactions **21**, 75 (1956)].

Using average values the reflected components of illumination are as follows:—working plane—5.32 lm/ft², ceiling—6.49 lm/ft², walls—5.82 lm/ft². It does not make much difference, particularly on the walls, but I think the practising engineer is always more at home with average values, where admissible.

The use of direct ratios to calculate the direct illumination is, I think, wonderfully optimistic. When using the Designed Appearance Method the engineer would want to be able to select from a wide range of luminaires. Direct ratios take time to calculate. I prefer a method which utilises the minimum of photometric data, i.e. the three-curve component light output ratios. I recommend Phillips' version of Mr. Waldram's method which uses my own Surface Distribution Factors.

For a ceiling or other light cavity a better approximation is given for equivalent reflectance by using absorption, *viz* :—

$$\text{equiv. refl.} = 1 - \left(\frac{\text{Cavity wall} + \text{ceiling area}}{\text{cavity ceiling area}}\right) (1 - \text{actual reflectance})$$

D. E. Spencer gives an interesting paper on this subject which would be a valuable addition to the references [*Illuminating Engineering*, **52**, 35 (1957)].

Cavities between the sides of furniture and floor can be simply treated by assuming the sides of the furniture to have zero reflectance. The sides are usually very dark or are themselves highly absorbing cavities. In the discussion on the above paper, O'Brien and Howard gave a formula for black sides.

Regarding the glare formula, I would have thought that ceiling luminance is not suitable for the adaptation value, because I understand from previous reading that in evaluating discomfort glare a horizontal line of sight is usually assumed, otherwise if you look up even the best installation would be a source of discomfort glare. Due to eye-brow cut-off, to suit a horizontal line of sight, I would recommend a value between the opposite wall luminance (6.16 ft-L) and perhaps the reflected component (5.81 ft-L) for small sources and the total for large area sources, say 5.99 ft-L in this case. This difference could have a bearing on the assessment of the glare index. The limiting value on the work sheet is not clear ; is it 300 ? As the glare index formula is based on the BRS modified formula, it would be interesting in view of Hopkinson's Cornell lecture [*Illuminating Engineering* **52**, 305 (1957)] to know which of the multiple criteria or perhaps BCD it was based on, and what percentage of the occupants could be expected to be comfortable.

The author's observations on these points would be most value to all interested in the problem.

Could Mr. Waldram now design the architect for use with the method ?

Mr. J. M. WALDRAM (in reply) : The lighting engineers of the world are trying to build a road leading to luminance design, but it is being built in sections which join up one day. I have been down the route in a jeep from one end to the other, perhaps for the first time, and I believe that the road is practicable, though some parts are still very rough going. It will not carry fast traffic for many years yet, and it is perhaps premature to criticise the details of the preliminary sections of the work or to forecast too definitely the eventual forms of the joining-up process. We are still exploring.

* Transactions, Vol. 23, No. 2, 1958.

Mr. Croft has drawn attention to several points of interest, nonetheless worth making if some of them perhaps come under the above comment. For example, I pointed out that my method was in rough alignment with a part of the Jones-Neidhart method, which is certainly interesting. But I agree with him that the usefulness of this alignment may prove less valuable than appears at first sight, partly for the reasons he gives and also because the process of luminance design is likely to lead to arrangements of luminance and light distributions other than the uniform arrays for which the Jones-Neidhart method is conceived and to which alone it applies. He will have noted the proposal by the British subcommittee that Jones-Neidhart ratios should be quoted ; the manufacturers' views are to be ascertained.

The difference between Phillips' method giving average illuminations and mine giving spot values is not large enough to affect the design materially. I have recently investigated the distribution of interreflected light by my method and compared the two. The average value is largely affected by the values round the edges of the surface which represent a large area and where the adjacent surfaces have a big effect ; but the user is more concerned to look near the middle. My method is more flexible and allows the calculation of whatever may be wanted, whereas averages smooth out the individual values, and some difficulties, but can be deceptive. Mr. Croft is correct in pointing out that the value quoted in my curves relates to the middle of the shorter wall, and rightly points out that it makes little difference which wall is used in rooms of reasonable proportions.

I do not know any method of computing adaptation level, and have had to be content with estimations, using a line or lines of sight appropriate to the situation. For example, in the workshop quoted, for the case of the man engaged in work on the benches their luminance will predominate, but for the man looking across the room, a more nearly horizontal line of sight would be appropriate.

For Mr. Croft's other points I am grateful : they may be useful tools for the lighting engineer to have. His correction to the calculation of cavities is an improvement on mine. But in all this work it is, I think, essential to keep the end of the road always in sight. We have to achieve a design in a real room with real equipment, to satisfy real clients. In its very nature it is quite impossible to be precise in such a job, even in specifying what we want to do ; and while we should not admit known systematic errors one has to keep a sense of proportion. That is exemplified in the considerations of glare index. The only point of working out the glare index is to make sure that one is well away from the limit, whichever may be chosen ; if the answer is such that the difference between 6.16 and 5.99 is significant, then surely the answer is to be found on the back of some cars—" If you can see this, you are to damn close ! "

In reply to Mr. Croft's last question, I am more than ever convinced that we need men who are " lighting artists " and combine both aesthetic and technical understanding, though there may be not so many who are temperamentally fitted to do so. We shall only get them if we train them ; that is not my job. But I asked for them ten years ago in my Presidential Address.

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